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Design of dry coconut (*Cocos nucifera* L.) dehusking and deshelling machine components using solidworks simulation

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Abstract

The main objective of this study was to develop a conceptual automated solution for the labour-intensive processes of coconut dehusking and deshelling. This was achieved by utilizing simulation-based design techniques. The study centred on the utilization of Computer-Aided Design (CAD) as a fundamental tool for the visualization and simulation of the proposed mechanisms. This study has developed a comprehensive framework for assessing the potential feasibility of the simulated dehusking and deshelling processes by conducting thorough evaluations that encompass stress, displacement, strain, and safety considerations. The cylindrical design with spiral spikes was designed to remove husks efficiently. CAD helped to comprehend the mechanism's behavior, and subsequent analyses revealed that stress levels remained far below acceptable thresholds. The displacement and strain effects were negligible, providing the structural integrity of the simulated dehusking procedure. The design utilized strategically placed metal bars to improve contact points and effectiveness. The simulation-based assessments replicated the dehusking evaluations, confirming that stress, displacement, and strain remained within limits. This study shows that simulated automation in coconut processing has excellent potential and supports its real-world implementation. Computer-aided design (CAD) and thorough analyses ensured the safety and reliability of conceptual mechanisms and set a precedent for agricultural processing machinery. This study proposes a systematic approach to coconut processing that might change the industry by improving productivity and reducing manual labour.

Key words: Coconut dehusking, Solidworks simulation, mechanical properties, design optimization, horticultural automation, safety and efficiency

Introduction

Coconuts (*Cocos nucifera* L.) hold paramount significance in horticultural plants, given each plant part's multifaceted utility. Amid a spectrum of applications encompassing food, fibre, fuel, and structural components, the predominant role of coconuts lies in serving as a vital food source. The pivotal core, housing the coveted coconut meat, contributes to essential products such as oil, chips, and milk (Asha Monicka *et al.*, 2021). However, harnessing this potential hinges on the prerequisite task of extracting the coconut meat, necessitating the removal of both the husk and shell. Although time-honoured, this traditional approach of manual dehusking and deshelling presents challenges of labour intensiveness and jeopardizes worker safety by exposing them to potential injuries (Mishra and Mohanty, 2016). To address these concerns, the integration of machinery emerges as a possible solution.

In light of these imperatives, the current study has embarked on a comprehensive endeavour – designing and conceptualizing a machine adept at dehusking and deshelling dry coconuts. The formulation of this machinery draws upon critical physical and mechanical properties of coconuts, encompassing parameters such as size, thickness, as well as forces essential for husk removal and shell breaking (Naliapara *et al.*, 2021). In this endeavour, the potential of Computer-Aided Design (CAD) shines through. As a versatile tool, CAD expedites the machinery design process. The tool's prowess in 3D modelling enhances operational clarity and visualization. Moreover, CAD's simulation capabilities enable designers to subject their creations to diverse load scenarios, thereby validating the design's robustness. This simulation provides crucial insights into the performance of machine components under varying external forces, predicting potential points of failure and ensuring the suitability of materials.

These principles find validation in prior research efforts of Venkataramanan *et al.* (2014) who undertook the design of an automated coconut dehusking machine, wherein measurements of required forces informed component design, executed in 3D through Solidworks software. Subsequent simulation assessments using ANSYS WORKBENCH v12.0 validated its performance under diverse load conditions. Jakasania *et al.* (2017) extended this approach through finite element analysis of an inclined subsoiler, with CAD-based simulations facilitating optimized design and replacing extensive field testing. Rustam *et al.* (2022) reinforced the significance of CAD in machinery design, demonstrating its applicability in developing an electric sugarcane cutter through Finite Element Analysis.

This research embarks on designing a simulated dry coconut dehusking and deshelling machine, with CAD and simulation analysis forming the cornerstones of innovation. By leveraging these tools, the study endeavours to enhance the efficiency, safety, and overall functionality of coconut processing machinery.

Material and method

The following data was obtained from earlier research (Naliapara *et al.*, 2021) on dry coconuts, and is presented in Table 1 and 2.

Two main types of forces were used to determine the machine's power requirements and validate the components' design: husk removal force and shell-breaking force.

Table 1. Husk separation force values for dry coconut at various intervals

Parameter	Force (kN)		Average (kN)
	1	2	
Force at shell and husk joint	1.87	1.85	1.86
Force at middle of shell and husk surface (approx. 30% from shell)	1.01	0.99	1.00
Force near husk surface (approx. 60% from shell)	0.75	0.78	0.76

(Naliapara *et al.*, 2021)

Design of dehusking unit: While designing the dehusking mechanism, two key factors were considered: (a) the mechanism should remove the husk through a peeling action, and (b) the pair of dehusking rolls should be large enough to accommodate the maximum size of dry coconuts. To achieve the peeling action, it was considered to have a spiral of spikes around a cylinder. The diameter of the dehusking rolls was based on the size of dry coconuts, which was found to be an average of 134.07 mm (Naliapara *et al.*, 2021). However, for design purposes, a size of 155 mm was considered to allow for a margin of error. The rolls should have dimensions to accommodate that size of coconut while dehusking. The combined diameter of two dehusking rolls should be greater than the size of a large size coconut. Considering these factors, the cylinder of 89 mm diameter was selected as the base of dehusking roll. The length of dehusking cylinder was decided to be around thrice the length of large-size coconuts (200 mm) to give proper time for the complete dehusking of coconut. The length of the dehusking cylinder was kept as 620 mm. The spiked spiral was made from edge of sprockets. The sprockets were cut in half and the hub portion of the sprockets was then removed. The remaining edge of sprocket (12 mm+ around 1-2 mm of weld) was bent and weld on cylinder at 100 mm pitch (final dia. 115 mm). A shaft of 25 mm diameter was welded through whole cylinder to provide strength, support and drive to the dehusking cylinder (Fig. 1).

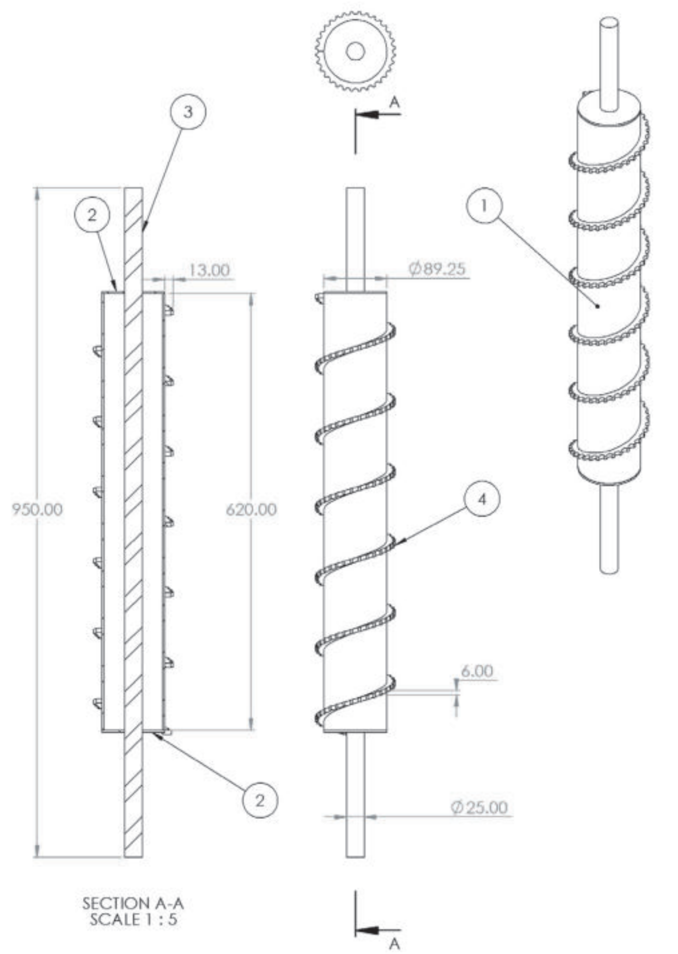

Fig. 1. Designed dehusking roll

Table 2. Dry coconut shell breaking force values

Sr. no.	Force (kN)
1	4.0
2	2.0
3	2.0
4	4.0
5	4.2
6	4.5
7	2.2
8	3.5
9	3.8
10	2.7
Average	3.29
SD	0.97

(Naliapara *et al.*, 2021)

Design of the deshelling unit: The deshelling cylinder size should be large enough to allow maximum points to come in contact with the coconut shell. To achieve that, the overall diameter of the deshelling roll should be greater than the diameter of the dehusked coconut. Also, the pair of rolls should break the coconut shells of various sizes. It was assumed that increasing the gap between rolls could facilitate coconut shells of small to large size. To make converging or cone-type cylinders is somewhat difficult. So, fixed-sized cylinders were selected and metal bars were cut in trapezoidal sections with edges cut in them and attached at the cylinders' periphery. The metal bars were cut and arranged so that one bar had a peak or edge on the periphery, and the next bar had a gap. The alternative arrangement increases the contact points on the coconut shell (Fig. 2).

Force acting on dehusking roll: The function of the dehusking roll is to remove the husk through a tearing action that results in peeling the husk from the coconut. The main force component responsible for that action would be torque. To remove the dry coconut husk by tearing action with a peeling effect would be 0.78 kN ≈ 0.8 kN. And the radius of dehusking roll is 57.5 mm. This would result in torque:

$$T = F \times r$$
$$T = 0.8 \times 57.5$$
$$T = 46 \text{ Nm}$$

To remove husk from dry coconut, the roll should exert 46 Nm torque thus it should be able to withstand 46 Nm torque when in operation.

Also, assuming that at any time two points of peripheral spikes would be in contact with the coconut husk during simulation, the torque applied on the dehusking roll would have two contact points on peripheral spikes. The shaft that is passing through the dehusking roll would be kept fixed during the study.

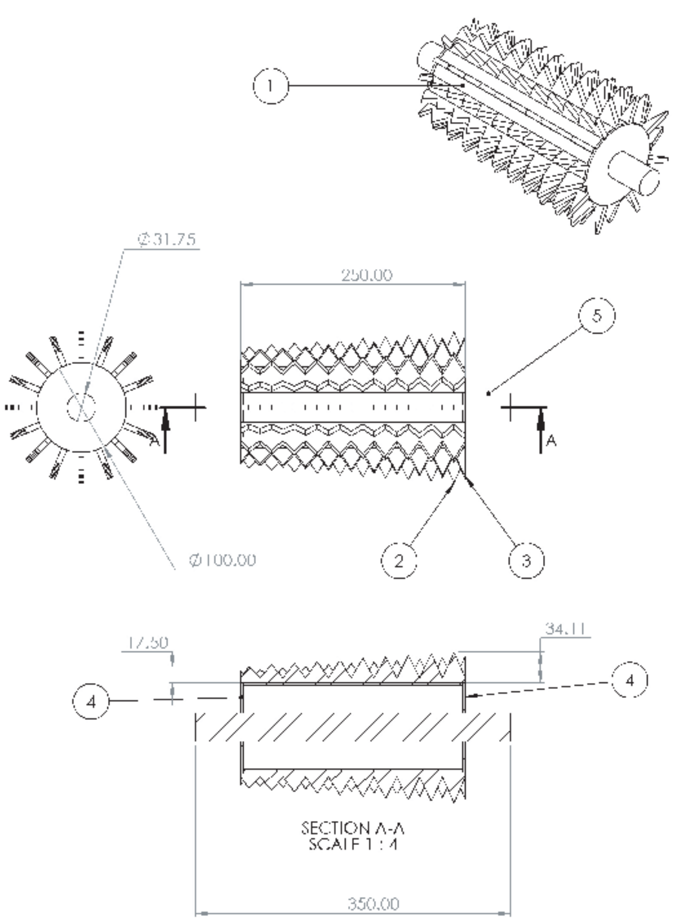

Fig. 2. Designed deshelling roll

Force acting on the deshelling roll: The function of the dehusking roll would be to break the coconut shell while rotating. According to UTM testing done by Naliapara *et al.*, 2021, the force required to break the coconut shell would be 4.5 kN, and the radius of the deshelling roll was 90 mm. The resulting torque to be:

$T = F \times r$

$T = 4.5 \times 90$

$T = 405$ Nm

To break open the coconut shell, the deshelling roll would exert 405 Nm force thus, it should be able to withstand 405 Nm during operation.

Assuming that two spike blades would come in contact with the coconut shell during the deshelling operation. Also, the main supporting shaft passing through the cylinder would be kept fixed during simulation evaluation.

Simulation study

In the simulation process using Solidworks software, there are three key parameters to consider: 1) fixture, 2) placement of external loads, and 3) meshing. The fixture defines the given body's movement characteristics. In this case, both the assemblies were given fixed geometry fixtures. The placement of the external load is important because it determines where the applied force will act, and the overall behaviour of the simulated system under the applied force will depend on the location of the load. The process of dividing the simulated object into smaller pieces is called meshing. Finite element analysis programs look at the model as a network of interconnected elements and solve the applied load's effect basis on these small interconnected elements.

Simulation study of dehusking unit: The main supporting shaft passing through the dehusking cylinder was considered a fixed geometry member. The shaft was the main supporting member of the whole dehusking cylinder assembly. The shaft material was proposed as AISI 1020 steel. For placement of external loads, it was assumed that the coconut would encounter at least two peripheral teeth during the dehusking operation. Also, the mid-section of anybody might be most susceptible to failure as the external load is applied to it. Two peripheral teeth were selected around the middle of the whole assembly as an external toque was applied during the dehusking operation. Meshing is one of the most important components of any simulation analysis as it breaks down the whole component into smaller manageable components for analysis. Solidworks lets users adjust the quality of meshing for the desired purpose. The highest meshing quality was selected for this analysis to get more accurate results. The materials proposed for constructing the dehusking unit components and their mass density and yield strength are listed in Table 3. The fixture, applied load, and mesh model are shown in Fig. 3.

Simulation study of deshelling unit: It was assumed that the

Table 3. Proposed materials for construction of dehusking unit and their properties

Material	Associated part	Mass density (kg/m^3)	Yield strength (N/mm^2)
Galvanized Steel	Main base cylinder (no. 1 in Fig. 1)	7870	203.94
Cast carbon steel	End caps of cylinder (no. 2 in Fig. 1)	7800	248.16
AISI 1020	Main supporting shaft through cylinder (no. 3 in Fig. 1)	7900	351.57
AISI 1045	Peripheral teeth for husk tearing (no. 4 in Fig 1)	7850	530

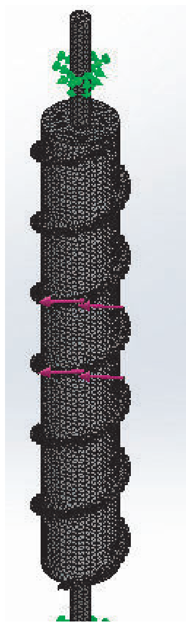

Fig. 3. Mesh model, fixed member (by green narrows) and applied torque (indicated by pink arrows) in dehusking roll

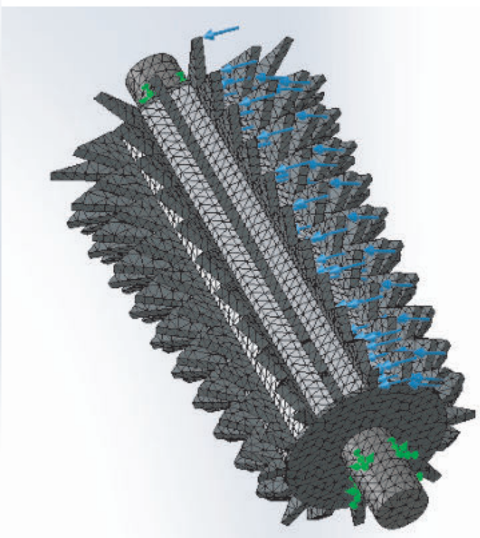

Fig. 4. Mesh model, fixed member (by green narrows) and applied torque (indicated by blue arrows) in deshelling roll

Table 4. Proposed materials for construction of the deshelling unit and their properties

Material	Associated part	Mass density (kg/m^3)	Yield strength (N/mm^2)
Galvanized Steel	Main base cylinder (no. 1 in Fig. 2)	7870	203.94
Cast carbon steel	End caps of cylinder and peripheral teeth for shell breaking (no.2, 3 and 4 in Fig. 2)	7800	248.16
AISI 1020	Main supporting shaft through cylinder (no. 5 in Fig. 2)	7900	351.57

deshelling unit might encounter higher stress due to the nature of the operation. The shell-breaking process requires more force than the dehusking unit, so the components of the deshelling unit subassembly were designed to be stronger and more durable. The thicker main supporting shaft passes through the selected fixed geometry member in the deshelling unit. In the deshelling unit, the peripheral toothed blades would come in contact with coconut shells; thus, two rows of teeth were selected for external load application. Like the dehusking unit, the highest meshing quality was selected for more accurate results. The fixture applied load and mesh model are shown in Fig. 4, and the proposed materials to build the deshelling unit components is given in Table 4 with their mass density and yield strength.

Result and discussion

This section discusses the report generated by solidworks and the component's response to the force applied on them. The four resultant components are discussed: 1) Stress distribution, 2) Displacement, 3) Strain distribution and 4) Factor of safety.

Finite element analysis result of dehusking roll

Stress distribution in dehusking roll: As per data presented in Table 5 the maximum stress observed at the end of the analysis was 37.71 N/mm^2 (MPa). The stress value should be less than the yield strength of the weakest material used in component making. The majority of stress distribution was observed on (Fig. 5) blade component where the coconut surface would touch it during dehusking, the nearby region of contact on the base roll and on the shaft – base roll contact. For the dehusking roll, the minimum yield strength was observed in main base cylinder's galvanized steel, 203.94 N/ mm^2 (MPa). The stress observed during analysis (37.71 N/mm2 (MPa)) is less than the yield strength of the material. According to this data, the design and material selection of the dehusking roll were safe on stress basis.

Table 5. Finite element analysis result of dehusking roll

Name	Type	Min	Max
Stress	VON: von Mises Stress	-	37.71 N/mm^2 (MPa)
Displacement	URES: Resultant Displacement	-	0.0087 cm
Strain	ESTRN: Equivalent Strain	-	0.00016
Factor of Safety	Automatic	5.21	-

Displacement: Displacement of machine parts causes the machine to function with error and reduces its efficiency, or sometimes it may lead to failure of the machine (Fig. 6). In the case of the dehusking roll, the displacement was observed as 0.0087 cm = 0.087 mm. The resultant displacement is negligible compared to the length (950 mm) and diameter (115 mm) of the dehusking roll. So, based on this resultant data, it can be said that the design and material selection of the dehusking roll were safe.

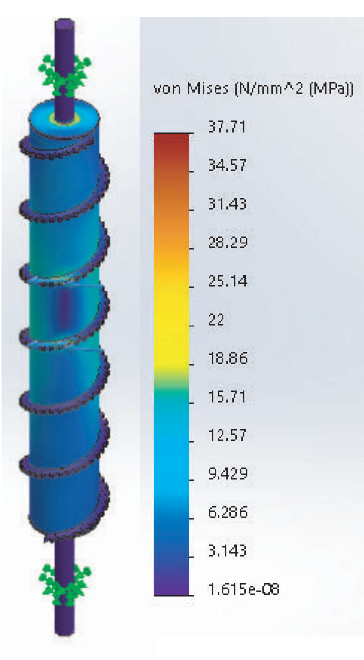

Fig. 5. Stress distribution in dehusking roll

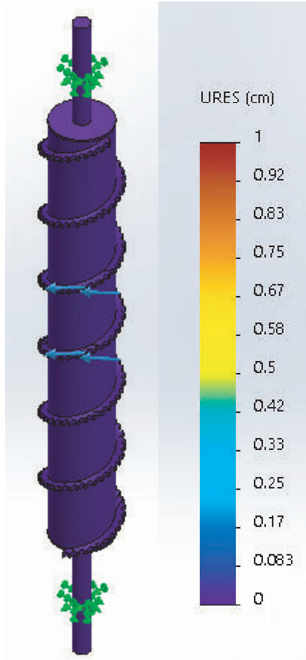

Fig. 6. Displacement in dehusking roll

Strain: The value of strain obtained as the result of the analysis was 0.00016, which can be considered negligible, and thus, the design could be regarded as safe for operation (Fig. 7).

Factor of safety : The resultant factor of safety was observed as 5.21 minimum (Fig. 8). The observed factor of safety value can be generally considered as safe.

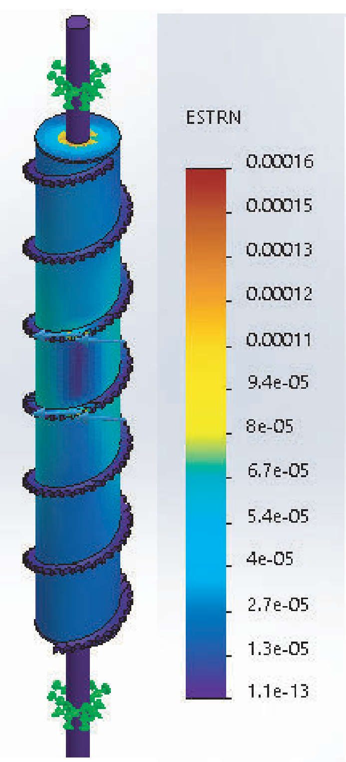

Fig. 7. Strain distribution in dehusking roll

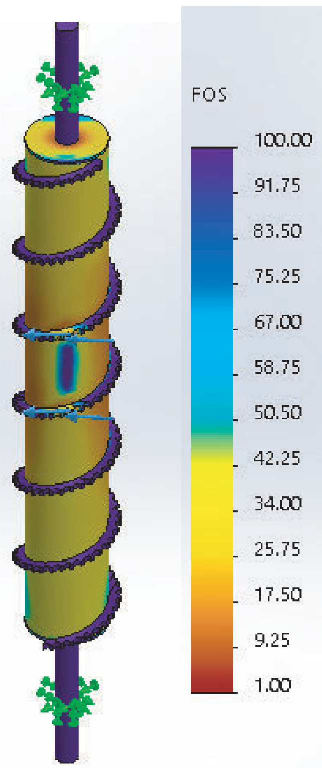

Fig. 8. Factor of safety distribution in dehusking roll

Finite element analysis result of deshelling rollstress distribution in deshelling roll: As per data presented in Table 6 the maximum stress observed at the end of the analysis was 91.5 N/mm^2 (MPa). The stress value should be less than the yield strength of the weakest material used in component making. The majority of stress distribution was observed on (Fig. 9) blade component – main base cylinder contact where the coconut surface would touch it during deshelling and on the shaft–base roll contact. For the deshelling roll, the minimum yield strength was observed in the main base cylinder's galvanized steel, 203.94 N/ mm^2 (MPa). The stress observed during analysis (91.5 N/mm2 (MPa)) is less than the yield strength of the material. According to this data, it can be said that the design and material selection of the deshelling roll were safe on a stress basis.

Table 6. Result of simulation values for deshelling roll

Name	Type	Min	Max
Stress	VON: von Mises Stress	-	91.5 N/mm^2 (MPa)
Displacement	URES: Resultant Displacement	-	0.0065 cm
Strain	ESTRN: Equivalent Strain	-	0.00042
Factor of Safety	Automatic	2.43	-

Displacement: In dehusking roll, the displacement was observed as 0.0065 cm = 0.065 mm (Table 6). The resultant displacement is negligible compared to the length (250 mm) and diameter (180 mm) of the deshelling roll (Fig. 10). So, based on this resultant data, it can be said that the design and material selection of the deshelling roll were safe.

Strain: The value of strain obtained as the result of the analysis was 0.00042 (Table 6), which can be considered negligible, and thus, the design could be considered safe for operation (Fig. 11).

Factor of safety: The resultant factor of safety was observed as 2.43 minimum (Table 6 and Fig. 12). The observed factor of safety value can be generally considered as safe.

In summary, this research focuses on the simulated design of a dry coconut dehusking and deshelling machine, leveraging Computer Aided Design (CAD) and simulation analysis. By incorporating essential coconut properties and CAD modelling, the research enhances visualization, while simulation analysis provides insights into component performance under varying loads, minimizing failure risks and ensuring material suitability. Preceding research, such as automated dehusking designs and CAD-driven simulations, reinforces the study's methodology. Overall, this work contributes to the development of a simulated machine, promising improved efficiency and safety in coconut processing through innovative design and simulation techniques.

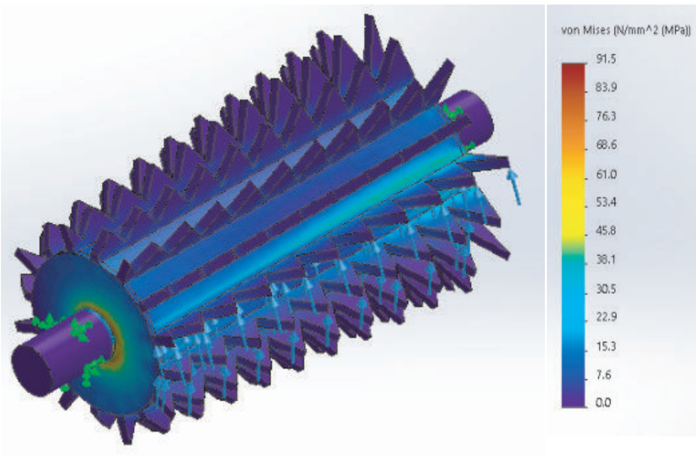

Fig. 9. Stress distribution in deshelling roll

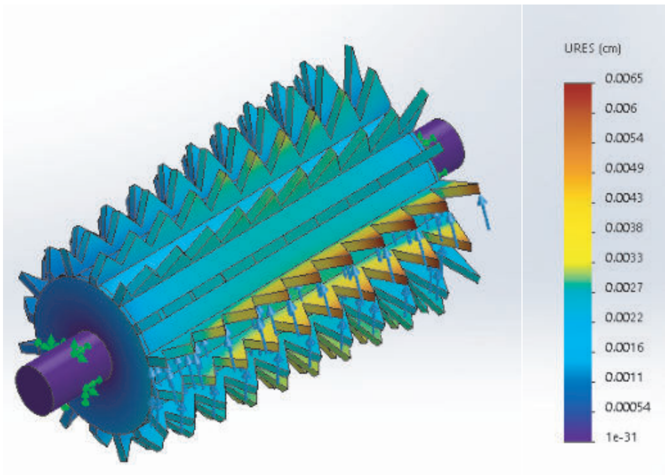

Fig. 10. Displacement in deshelling roll

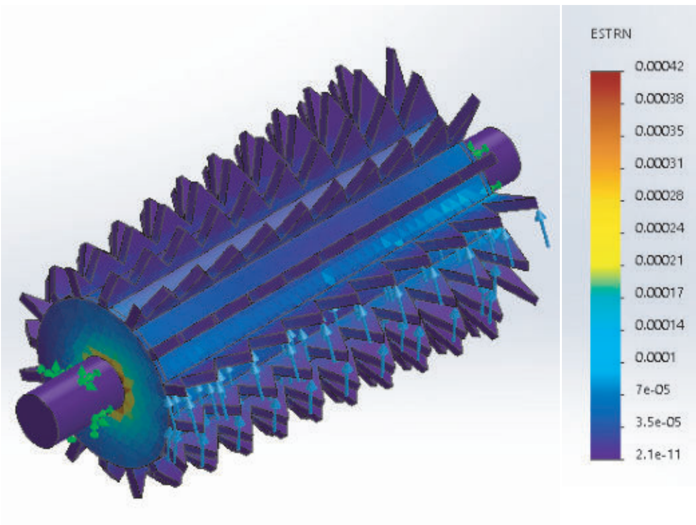

Fig. 11. Strain distribution in deshelling roll

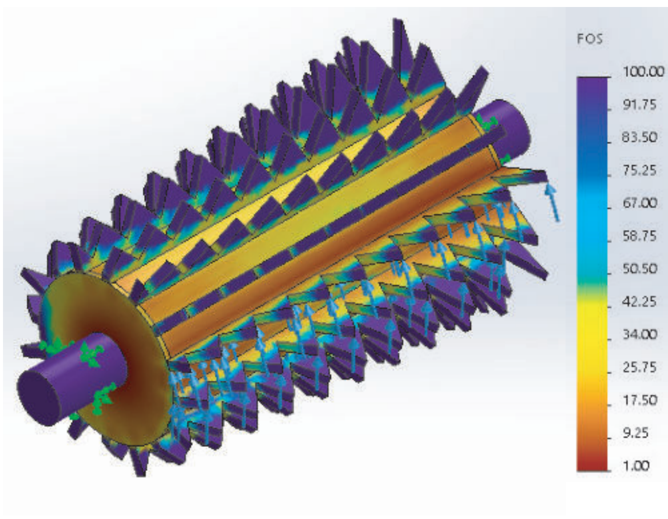

Fig. 12. Factor of safety distribution in deshelling roll

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