Orchard wastes shredder for smallholders using ANSYS

Hani Mehanna[1], Shang Shuqi[2], Maher Attia[1], Wang Jiasheng[2], and Adel G. Abdel-Razek [3]

(1. Agricultural and Biological Division, National Research Centre, Dokki, Cairo, 12622 , Egypt;
2. Mechanical and Electrical Engineering School, Qingdao Agricultural University, Qingdao, 266109, China;
3. Fats & Oil Department, National Research Centre, Dokki, Cairo, 266109 ,Egypt)

Abstract: Compost has the main role inEgyptian organic farming, and its demand rapidly increased. But for small-scale orchards, it is a problem, many Egyptian orchards are small farms (⩽ 0.5 ha), suffering from the lack of small-size shredders. Wastes particle size has an impact on the compost industry. Therefore the main object of this project was to design and manufacture a shredder and produce uniform raw material proper for making good compost in a short time. The prototype shredder could control the thickness of shredded orchard wastes according to the needs of compost producers to recycle orchard wastes (max. 5 cm diameter). The shredder machine consists of a frame, hopper, cutting shaft, cutting support, 2 pulleys, belt, and motor. The main part is the cutting shaft and the cutting support which gives the ability to control the thickness of shredded waste. The ANSYS program was used to analyze the shear stress, total deformation, and equivalent stress (Von Mises) to choose the proper material for the cutting shaft to do such an operation. The maximum shear stress, equivalent stress, and displacement deformation on the wood bulk were obtained using stainless steel material, followed by cast iron then structure steel, for that the recommended material for the shaft was structure steel and for the cutting knives was stainless steel. The cutting support is flexible to have the desired thickness of the cut material, but the study focused to get 2 mm thickness according to the compost expertise demand, but the machine could cut the wastes up to 4 mm thickness. The shredder machine operation was to feed the orchards wastes (tree branches max. 5 cm diameter) to a hopper at a 45^{o} angle between the adjustable support (protruding), and the shaft with sharp cutting fixed knives, to cut the wastes depending on the shear stress between the wood and the knives, then the cut pieces will grumbling down by the shaft acceleration and gravity in the bottom of the shredder to be collected later.

Keywords: shredder, orchards wastes, ANSYS, compost.

Citation: Mehanna, H. M.,S. Shuqi, M. Attia, W. Jiasheng, and A. G. Abdel-Razek. 2022. Design orchard wastes shredder for smallholders using ANSYS. Agricultural Engineering International: CIGR Journal, 24(4): 30-40.

1 Introduction

Recently in Egypt, compost is the most important organic fertilizer, especially for sandy soil farms. Whereas the chemical fertilizers are not cheap, moreover organic fertilizer improves the physical properties of the sandy soil. Also, approximately 18% of the agricultural wastes are used directly as an organic fertilizer sources,and a 30% portionis used as animal feed (El-Mashad et al.,2003).

Received date: 2020-02-10 **Accepted date:** 2022-09-03

***Corresponding author:** Hani Mohamed Mehanna, Associate Professor of Agricultural Engineering Researcher, Department of Water Relations and Field Irrigation, Agricultural and Biological Division, National Research Centre, Cairo, Egypt. Tel: +201124998404. Email: mr.mehana@gmail.com

Zayani (2010) had estimated that 2010's demand for compost in Egypt, was around 53 million ton annually for the old Nile Valley land and 1.5 million ton a year for reclaimed land, and the demand for compost for reclaimed desert land was expected to reach at least 30 million ton by 2017, now the demand is more than this amount. With the present national production capacity of compost being only about 20.7 million ton per year, there is a major shortage inthe supplyofcompost. Abou Hussein and Sawan(2010) reported that the major factors affecting the decomposition of organic matter by micro-organisms is oxygen and moisture. The other variables affecting the process of composting are nutrients (carbon and nitrogen), pH, time and the physical characteristics of the raw material (porosity, structure, texture and particle size).Orchards pruning wastes have a huge number of tons in Egypt. Thus using these wastes for compost production is a very useful and environmentally friendly method. Most orchard farms are smallholdings, and there is a bad impact on their orchards and environment if they do not use their orchards wastes in the right way, thus shredder machine turns these wastes to useful material, and accelerates the process of composting by increasing the surface area of residues for aerobic degradation thereby reducing the time to obtain the compost (after 3 months). Many designers all over the world do plenty of designs and manufacturers make a big industry of this kind of machines, such as Handeand Deshpande (2014), they carried out the project on the methodology for design and fabrication of portable organic waste chopping machine. Orchard waste is fed uniformly through a feeding drum and tray, then the shaft rotated at 1440 rpm through an electric motor by some pulleys which move the chopping drum to cut the waste by the effect of shear stress. The cut is also made inside the chopping house due to the effect of tensile, friction, and impact effect in chopping process. The cut pieces pass through the concave holes of the sieve and come out under the machine.

Naik et al. (2014), focused on the fabrication of areca fiber extraction machine, this is removing fiber from the areca husk. That machine consists of 3 phase 5 hp AC motor which is directly attached to the driven shaft. The driven shaft is enclosed in a casing that is designed in such a way that only dust is removed and fiber falls of a rectangular duct. The driven shaft is supported by two bearings and has blades, is designed by modifying the blade design to fit the coconut husk deco-rticating machine. The obtained areca fiber has good quality with a diameter varying from 0.39 ± 0.12mm and length varying from 5-6cm. Thus that machine will be helpful for rural farmers. Nithyananth et al.(2014),have developed a design of waste shredder machines. The waste shredder machine was attached to the tractor. The shredder can be operated with a tractor power take-off shaft (PTO).The tractor’s power was 35 hp. The Assembly consists of one fixed blade and five circular blades. The organic matter shredded will be cut in small pieces to enable the farmer to make vermin compost. Kumar and Kumar (2015) designed and manufactured an agricultural waste shredder machine focus on chopping coconut leaves, and areca leaves to prepare the vermin compost, where the electrical power was transmitted to the cutter shaft through a belt drive then they used 8 cutters, mounted on two shafts, which rotate and driven by a spur gear.

Fauzia et al. (2017) detailed study of various parts of shredder machine like stand (frame), transmission system and cutting system are made and designed separately using “SOLIDWORKS 2014” and its motion study and the analysis of the stand in ANSYS 15. Nasr and Yeiha (2019) implemented Finite Element Analysis with ANSYS to study shredder blade attached with three cutting edges.

This research work aims to design and manufacture a small and cheap shredder to cut the orchard wastes into pieces proper to obtain the compost quickly.

2 Materials and methodology

2.1 The machine design

This machine was designed by a team work from the National Research Centre, Egypt, Mechanical and Engineering College, Qingdao Agric. University, China, according to the following steps:

1.Determination of the orchard wastes, maximum and minimum diameter.

2.Deducethe optimal thickness of the raw material for vermin compost.

3.Shredder Design process.

4.The shaft and cut knives specifications using Finite Element Analysis of ANSYS program.

5.Manufacture and test the designed mach-ine.

2.2 Determination of the orchard wastes in Egypt

A survey for Egyptian orchards was done located in Nubaria sector, El-Buheira, Egypt (the average area of orchards ranged from 0.5 ha to 1 ha). Three samples were randomly collected from the visited orchards of different fruit tree types (such as peach, apple, orange, grapes and mango) with 10 kg weight for each sample(the cut branches from the pruning process), and the diameter of the orchard wastes was well recorded in the range from 0.5 cm to 5 cm max. Fifty percent of the samples were fresh cut wastes to express the softwood samples (35% - 40% moisture content), and the rest were collected from the last year's cut wastes expressing the hardwood (2% - 5% moisture content).

2.3 Deduce the optimal thickness of the raw material for vermin compost

Another survey has been done to determine the optimal thickness and length of the used raw material for vermin compost, which affects the compost process period. This machine will give the ability to the smallholders to change the thickness of the cut pieces, to accelerate the composition process. For that, this study only focused to have 2mm thickness of cut material.

2.4 Design process

The design was studied according to the mentioned above two steps, the dimensions of the frame, the cutting knives, the power source, and the pulleys.

The theory of the shredder machine operation was to feed the orchard wastes (tree branches max. 5 cm in diameter) to the hopper toward a shaft with sharp fixed cutting knives and a support (protruding) to cut the wastes depended on the shear stress between the wood and the fixed knives on the main shaft, then the cut pieces will grumbling down by the shaft acceleration and gravity in the bottom of the shredder to be collected later, avoiding the machine clogging. The support should be adjustable to give the user the ability to choose the proper thickness of the cut wastes (1, 2, or 3 mm) by adjusting the clearance between the protruding and knives before operating.

Figure1 shows the studied forces on the body diagram of the main shaft, and the required cutting force (Fc) for wood which was determined by Cristovao (2013), it was 190 N. And the free body diagram was drawn to calculate the maximum bending moment and the max shear stress, 51525 Nmm, and 18309 Nmm, respectively.

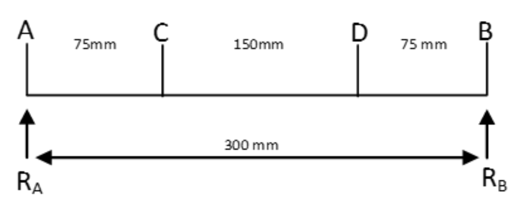


Figure 1 Free body diagram for the designed shaft

2.5 The shaft and cut knives specifications using Finite Element Analysis of ANSYS program

The technique of Finite Element Analysis and Explicit dynamics analysis have been used in ANSYS (18.1) program to define the materials of the cutting knives. Therefore two kinds of wood specifications would be used, as well as 4 types of metal were studied (Table 1).Two components were modeled, the knives with 2mm depth and the wood block with 5 cm diameter with the fixed support and 45^o feeding angle, to study the total deformation, equivalent stress (von mises), and shear stress on which will occurfor the wood bulk under the effect of shaft weight and the required force to cut the wood bulk (190 N).

Table 1 Specifications of wood* and knives materials to feed in the ANSYS program**

Material	Density, kgm^{-3}	Young's Modulus, Mpa	Poisson's Modulus
Softwood	800	5500	0.050
Hardwood	1400	10900	0.086
Structure Steel	7850	2.000×10^5	0.300
Cast iron	7200	1.100×10^4	0.280
Stainless steel	7750	1.693×10^5	0.310

Note: * Wood Handbook: Wood as an Engineering material, 2010
** Avallone et al. (2007)

In general, the behavior of the blades was changed from knives' material to another also by using the different wood materials. From Figures2-4, it is clear that softwood is easier than hardwood to cut and it is logical. For that, the selection was related to the analyses using the hardwood, for safety and the maximum loads. Figures5 and 6 show the effect of using different materials of knives on the wood bulk. The maximum shear stress and Equivalent stress were gained using stainless steel material (452.89 Mpa, and 4524.60 Mpa, respectively), followed by the cast iron material compared with the other studied materials. In the same concern, the max displacement deformation which occurred on the hardwood bulk was obtained using stainless steel material. Meanwhile using the lowest values of shear stress, equivalent stress, and displacement deformation have been detected using structural steel material. Therefore, the recommended material for manufacturing the shaft was structure steel and for the cutting knives was stainless steel.

As explained in Table 1, two wood materials and three knife metals were selected to study the behaviour of the operation process, as shown in Figure 2-a, and 2-b using cast iron material, Figure3-a, and 3-b using stainless steel material, and Figure4-a, and 4-b using structure steel material for knives to cut softwood and hardwood, respectively.

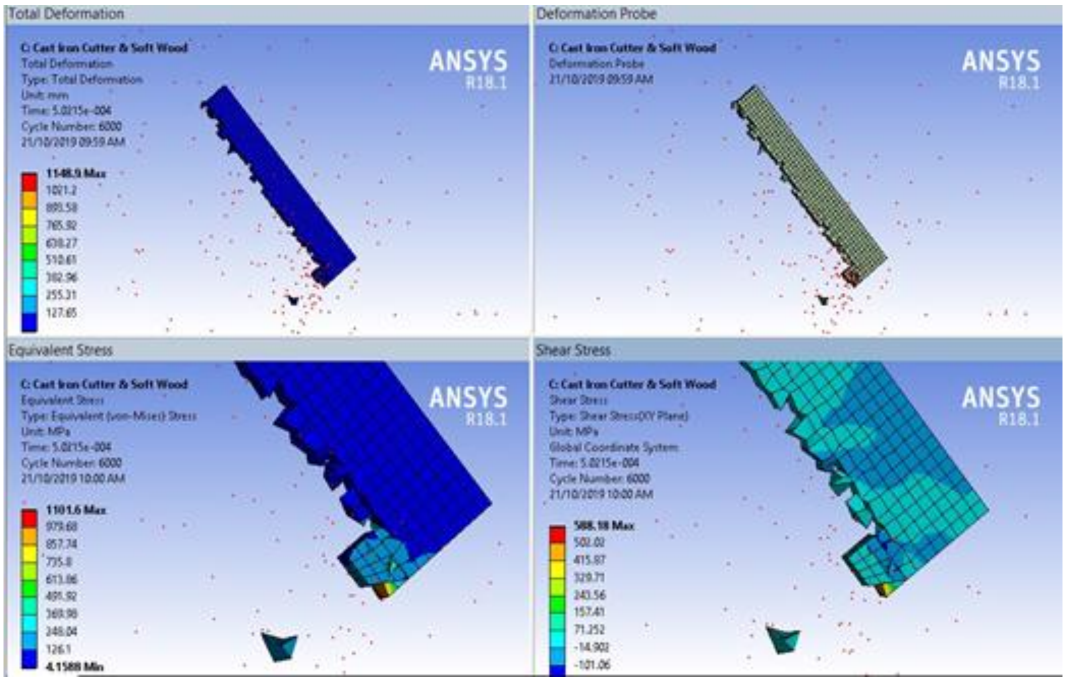
Figure7 shows the designed specifications for the shaft, where its length is 30 cm, 5 cm diameter, and 3 cm in diameter for the two supports into the bearings, its material is structural steel. Two knives, 2 mm in thickness and 30 cm in length, are studded with the shaft, made of stainless steel.

Table 2 Small size orchards waste shredder design specifications

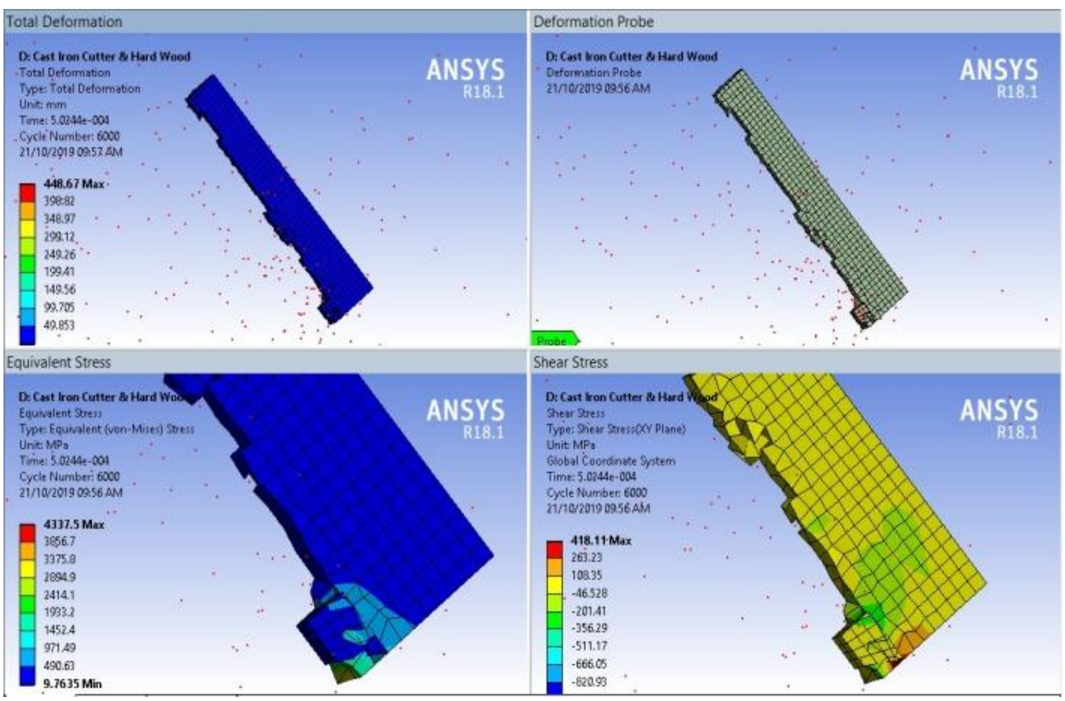
No.	Description	Specifications
1	Name	Small size orchard waste shredder
2	Mechanism	Pulley with belt drive attached to an electrical motor and shaft with two knives.
3	Material	Structure steel for shaft, stainless steel for the cutting knives, Mild steel for frame.
4	The motor	3 phase, 7 hp, 5.5 kw, AC motor, 2800 rpm
5	Pulley	3.5 cm diameter, pulley ratio 1:1 (2 pulleys)
6	Bearings	B 77 P207 (2 bearings)
7	Weight	180 kg
8	Production rate	28 – 66 kgh^{-1} (according to the wood hardness and motor speed)

2.6 Manufacture and test the designed machine

The designed shredder was manufactured in a local workshop, with the mentioned specifications in Table 2 and Figure8. Twelve samples of orchard wastes were collected; the weight of each was 10 kg, with a range of 0.5 cm to 5 cm in diameter. Half of the collected samples were fresh cut wastes, and the rest were old cut wastes from the last year; to express the softwood and hardwood, respectively. An inverter was used to operate the electric motor at two rotational speeds 1400 rpm and 2800 rpm, to calculate the elapsed time to cut each sample kgh^{-1}, as well as the consumption of power, kW.

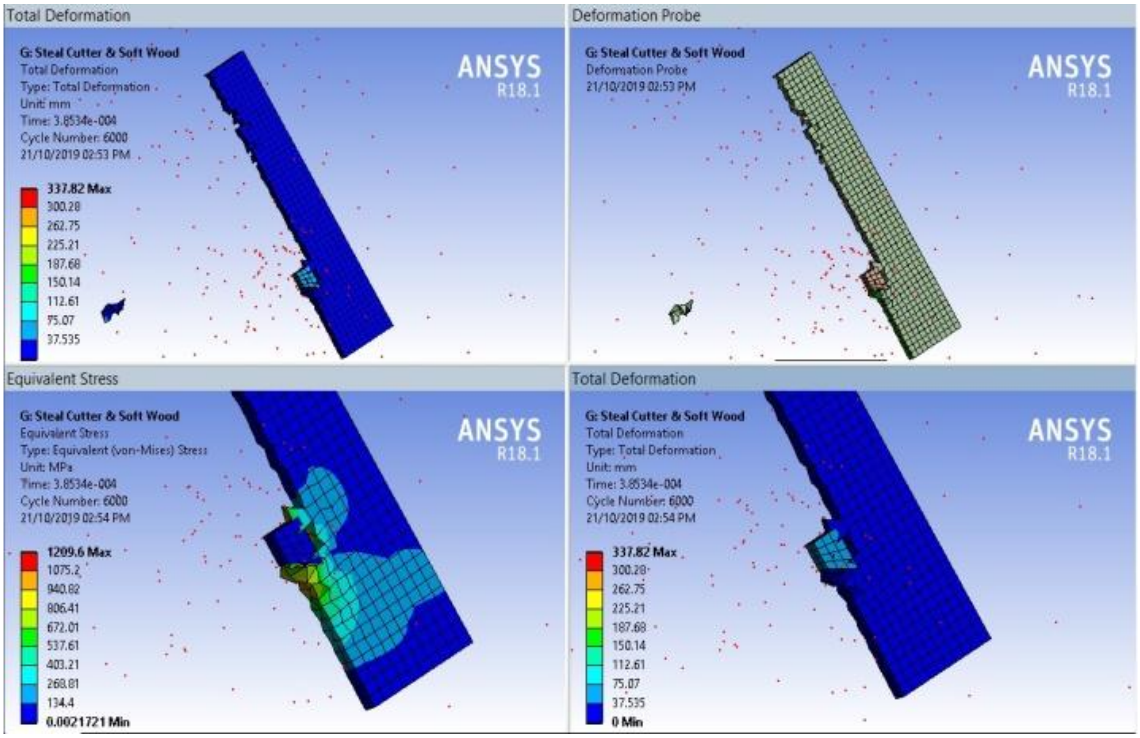


(a) Using cast iron material for knives to cut soft wood

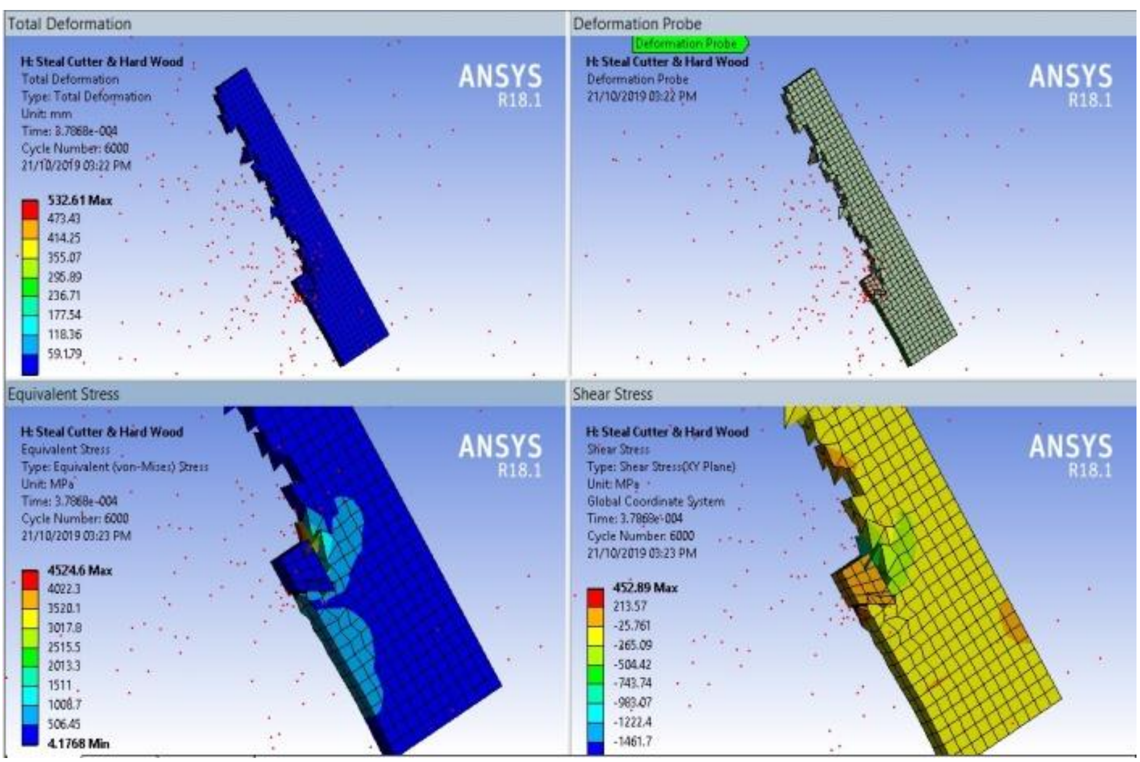


(b) Using cast iron material for knives to cut hard wood

Figure2 Using cast iron material for knives to cut different wood

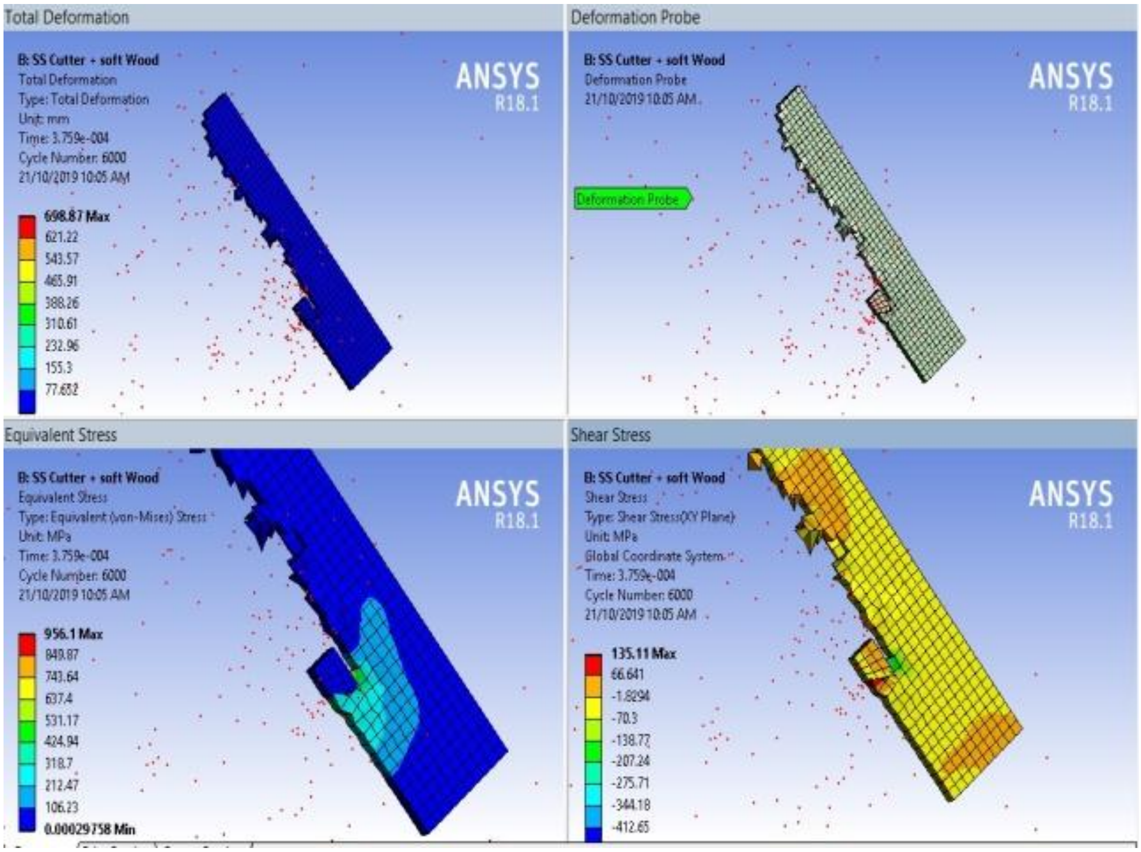


(a)Using stainless steel material for knives to cut soft wood

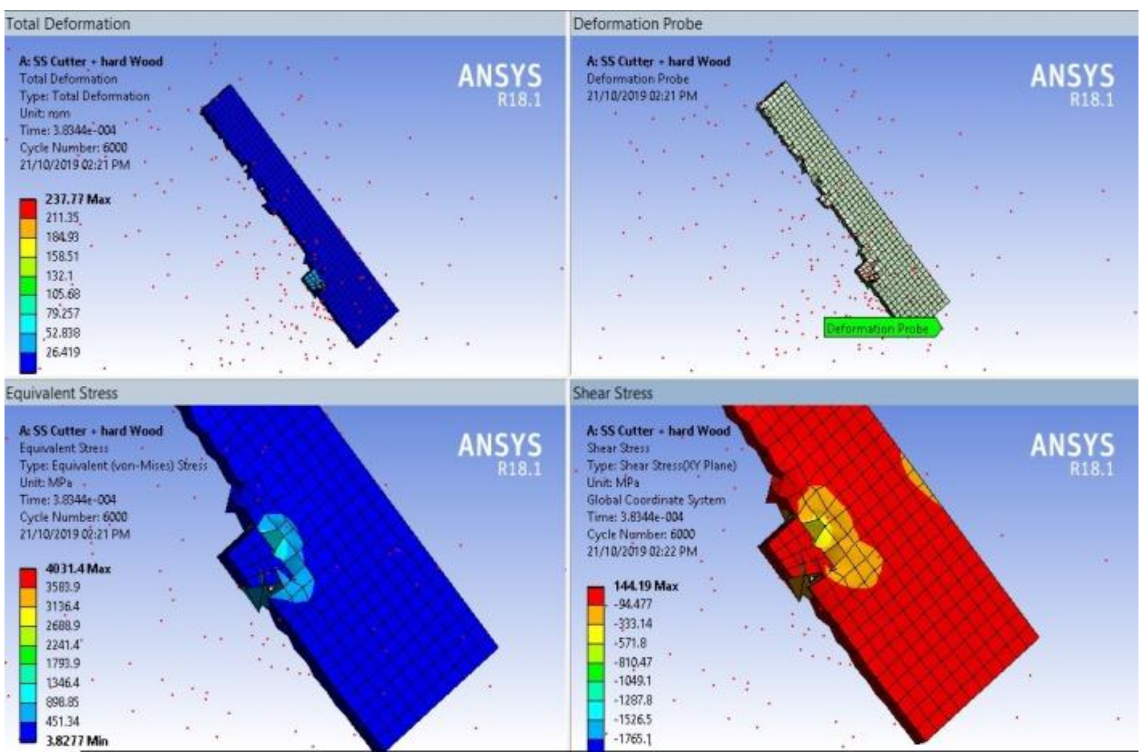


(b)Using stainless steel material for knives to cut hard wood

Figure 3 Using stainless steel material for knives to cut different wood



(a) Using structure steel material for knives to cut soft wood



(b)Using structure steel material for knives to cut hard wood

Figure 4 Using structure steel material for knives to cut different wood

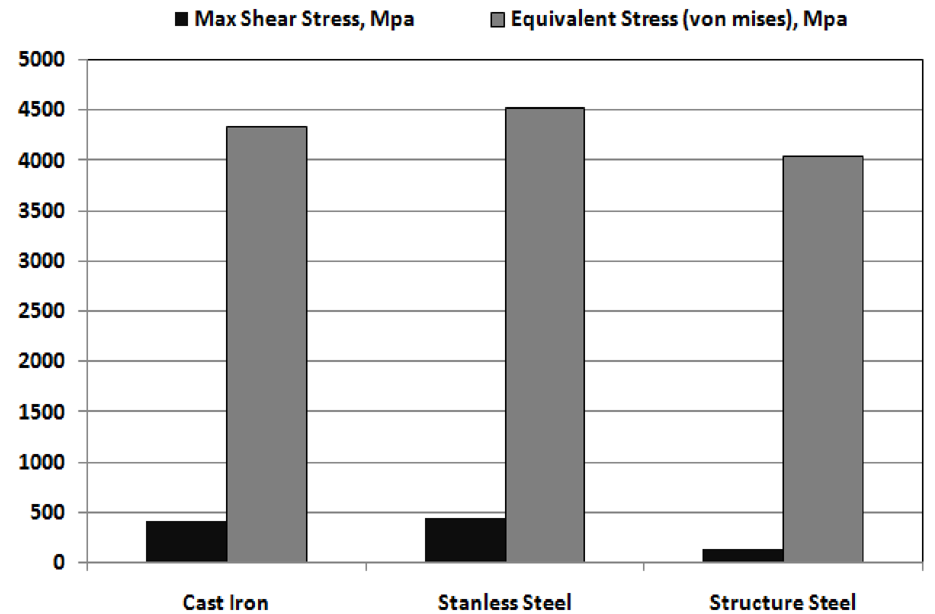


Figure5 The effect of using different materials of the cutting shaft on shear stress, equivalent stress of the hard wood bulk

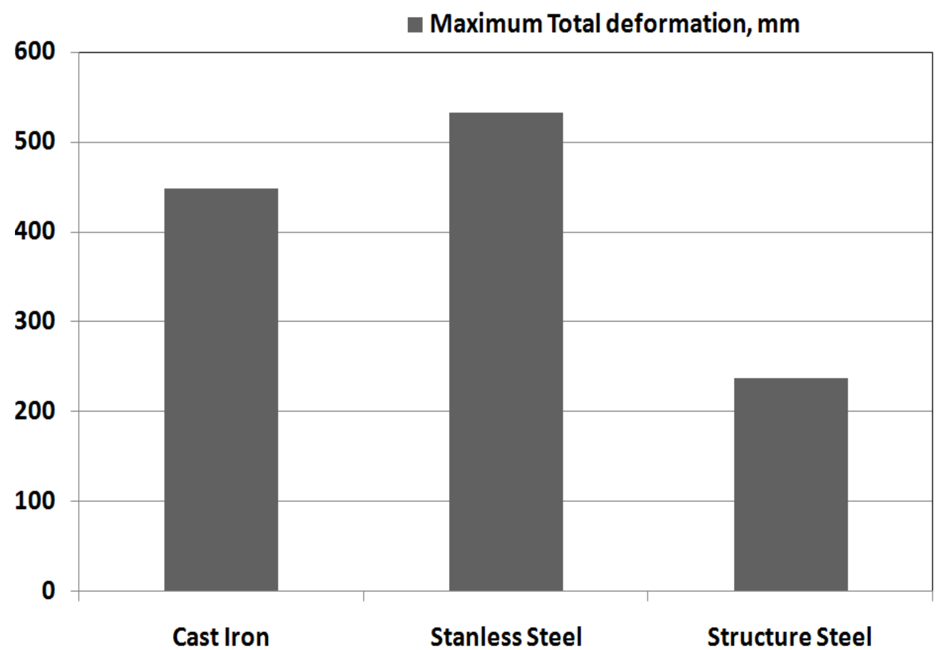


Figure 6 The effect of using different materials of the cutting shaft on displacement deformation of the hard wood bulk

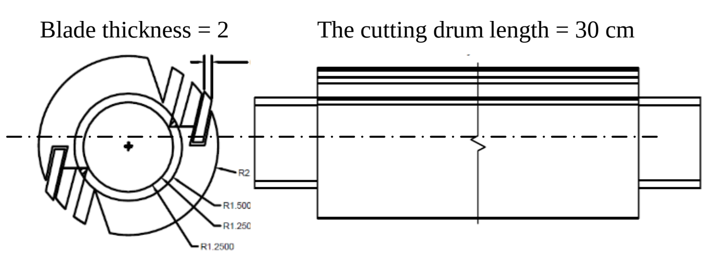


Figure 7 The cutting drum device with two knives fixed on it, with 5 cm outer diameter and 30 cm in length

3 Results and discussion

3.1 Specifications of the shredder machine

Figure8clarifies the manufactured small-size shredder machine. The model is connected to an electrical motor (7 hp) to gain the required mechanical power with safety, 3 phase, to cut the orchard wastes such as the tree branches which have been cut by pruning the trees with a maximum 5 cm in diameter. Then these wastes will be fed to the machine inlet and pushed toward the cutting knives which havea clearance of 2 mm with the iron support, having compost raw material with 2 mm thickness and a range of length from 2 cm to 3 cm.

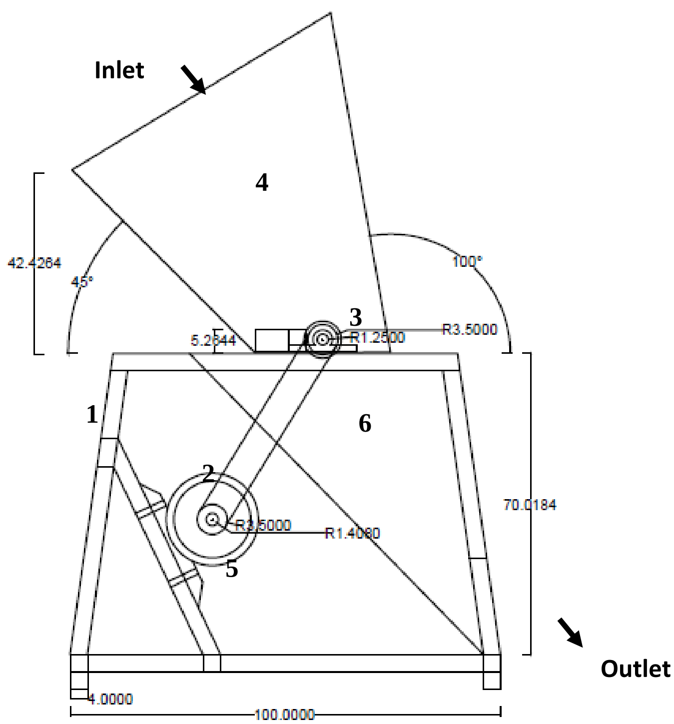
3.2 Test the shredder machine

The small-size orchard wastes shredder machine was tested to measure its performance under two rotational speeds.

Figure9 indicates the performance of the manufactured small-size orchard waste shredder to cut hard and soft wood samples (10 kg) under the two studied motor rotational speeds 1400 rpm and 2800 rpm, by estimating the elapsed time in min. The elapsed time to cut the 10 kg sample has been decreased by increasing the rotational speed from 1400 rpm to 2800 rpm, as well as softwood was easy to be cut compared with hardwood.

Figure10 gives an overview of the power consumption (kW), it was high to cut the hardwood, and with the highest studied rotational speed. On the other hand, the lowest power consumption was obtained by cutting the softwood by the lowest rotational speed. It is recommended that the farmer should use this shredder after the pruning process directly to cut the wastes in its soft conditions, 30% - 40% moister content.

These resultsare in the same trend with that reported with Hande and Deshpande (2014), Oladejo et al.(2020),and Kumar and Kumar (2015).



No.	Description
1	Main frame
2	The motor
3	The cutting drum
4	The hopper
5	The pulley
6	The belt

Figure 8 Developed model of the small size shredder machine for orchard wastes

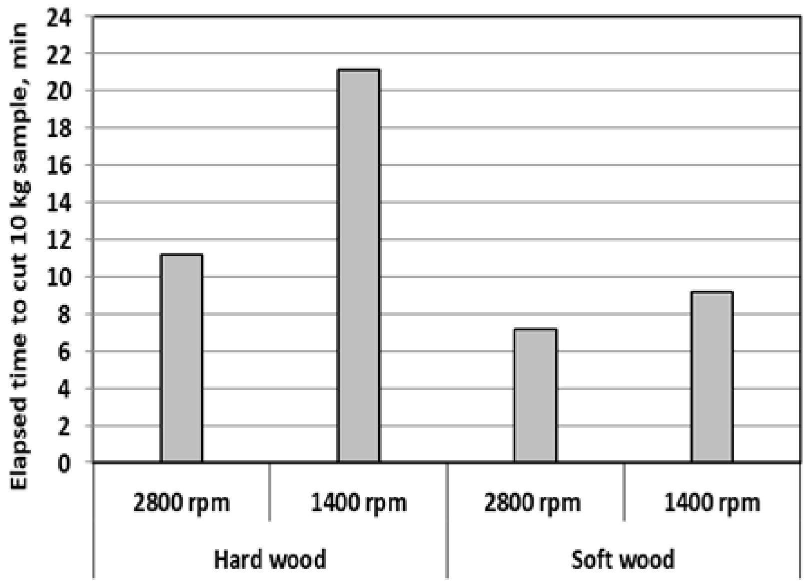


Figure 9 Average of elapsed time to cut samples (10 kg each) under the two rotational speeds

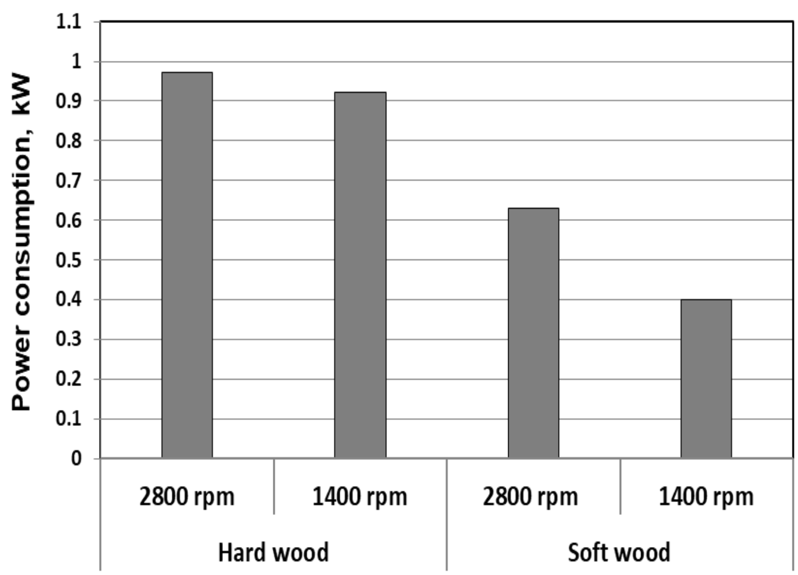


Figure 10 Average of power consumption to cut samples (10 kg each) under the two rotational speeds

4 Conclusion

The small-size orchards waste shredder machine was designed and locally manufactured. It consists of the frame, cutting shaft with two fixed knives, a hopper, and an electric motor attached to the cutting shaft using two pulleys and a belt. When the user feeds the orchard wastes such as tree branches (maximum 5 cm in diameter) through the hopper towardthe cutting device which has support with 2 mm in clearance, at the same time the motor (2800 rpm) moves the cutting shaft using the pulleys and the belt, the knives cut the branches to raw material for compost with thickness of 2mm and length of 2-3 cm, the cut woody material goes out from the machine bottom outlet. This shredder is locally manufactured, so it is a good opportunity for small orchard holders to start a small business and/or make their own compost.

References

Abou Hussein,S. D., and O. M.Sawan. 2010. The utilization of agricultural waste as one of the environmental issues in Egypt (A case study). *Journal of Applied Sciences Research*, 6(8): 1116-1124.

Avallone, E. A., T. Baumeister III, and A. M. Sadegh. 2007.*Marks' Standard Handbook for Mechanical Engineers*. McGraw-Hill.

Cristovao, L. 2013. Machining Properties of Wood: Tool Wear, Cutting Force and Tensioning of Blades. Ph.D. diss., Department of Engineering Sciences and Mathematics, Wood Science and Engineering, Luleå University of Technology, Sweden..

El-Mashad, H. M., W.K. P.van Loon, G. Zeeman, G. P.A.Bot, and G.Lettinga. 2003. Reuse potential of agricultural wastes in semi-arid regions: Egypt as a case study. *Reviews in Environmental Science and Biote-chnology*,2(1): 53–66.

Fauzia, S., H. Patil, S. Raut, O.Wadake, and S.Tandel.2017.Design and fabrication of paper shredder machine.*International Journal of Scientific & Engineering Research*, 8(3). 18-25.1

Hande, A. S., and A. A.Deshpande. 2014. Methodology for design & fabrication of portable organic waste chopping machine to obtain compost: a review. *International Journal for Innovative Research in Science & Technology*, 1(7): 132-135.

Kumar, I. M. S., and T. R. H. Kumar. 2015. Design and development of agricultural waste shredder machine. *International Journal of Innovative Science, Engineering & Technology*, 2(10): 164-172.

Naik, K., R. P. Swamy, and P. Naik. 2014. Design and fabrication of Areca fiber extraction machine. *International Journal of Emerging Technology and Advanced Engineering*, 4(7): 860-866.

Nasr, M.F.,and K.A. Yehia.2019. Stress analysis of a shredder blade for cutting waste plastics.*Journal of International Society for Science and Engineering*,1(1): 09-12.

Nithyananth, S., L. Samuel, N. Mathew, and S. Suraj. 2014. Design of Waste Shredder Machine. *Journal of Engineering Research and Applications*,4(3): 487-491.

Oladejo, A.E., S.I. Manuwa, and T.B. Onifade2020. Design and fabrication of a shredder, *IOP Conf. Series: Earth and Environmental Science*, 445(1): 012001.

Zayani, A. 2010. Solid Waste Management, Overview and current state in Egypt. Short paper # 5, Reviewed and edited by: Maggie Riad.