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DEVELOPMENT OF A MACHINE FOR CHOPPING WOOD RESIDUES

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ABSTRACT

CAD software and FEM analysis were used to modify the drum of threshing machine into machine for chopping wood residues. The operating parameters that affecting the performance of the chopping machine are drum speed (450, 1000 and 1200 rpm), three stages of serrated disk arrangement clearance between drum flail knives (0.7, 1.5 and 3 cm) and three levels of feeding capacity (W1 = 300, W2 = 360 and W3 = 420 $kg \cdot h^{-1}$). The developed machine was operated by the addition of two types of knives (sharp free knives + serrated discs) to the original knife existing already in the machine. The machine was evaluated in terms of production capacity, cutting efficiency, power requirements and energy consumption. Using the modified (serrated) saw disk mill and flail knives reduced the energy requirement for chopping and raised fine degree of the chopped materials and solve the clogging problem. The cutting productivity and cutting efficiency raised with reducing the clearance between flail knives (0.7, 1.5 and 3 cm) while the power requirements and energy consumption reduced.

KEYWORDS: CAD, FEM analysis, chopping machine, serrated disc mills, knives sharps and wood residues.

INTRODUCTION

The first step towards solving residues problem, in order to be used as lignocelluloses raw materials in several industries, is to cut, crush and mill these residues using hammer mill machines to minimize the volume (Bejo et al. 2009). Ariavie et al. (2010) stated that, the fine particles of biomass improve density and the quality of briquettes. A briquetting plant used to produce the briquettes from residues essentially have hammer mill consists of a rotating shaft with free- swinging hammers, which reduce the size of particle to a predetermined size. Anup et al. (2012) used the hammer mill hammers like projection mounted on a shaft. The hammer revolves at high speed to chop the materials fed into pieces by beating. The one end of shaft coupled with blower to transport the chopped material from mill.

CAD (computer aided design) means that is a project assisted by a computer. CAD is the use of computer technology to aid in the design of a product. CAD system develop project functions, mainly based on the design of the item which one wants to create by using a series of tools provided by a data processing system to improve the efficiency and speed of the operations which are usually made by hand. CAD offers solutions reduce product time-to-market and improve communication efforts between design and production. Cellulose is one of the highly abundant natural polymers found in earth. It can be extracted from several sources including bagasse, wood, cotton, pineapple leaves and sisal fibers amongst others (Linganiso et al. 2019). Several authors state that the wood density varies not only by tree species but also with the vertical or radial location within the trunk or in the tree crown (Husch et al. 2003, Tomczak, and Jelonek 2013) followed by the annual rings width, the proportion of early and late wood, the tree age and the site on which the tree grows (Zeidler and Borůvka 2016, Schönfelder et al. 2017 and Jelonek et al. 2009).

The main objective of this research is to modify the performance of hammer mill equipment during cutting and crushing wood residues.

MATERIAL AND METHODS

A local hammer mill machine was developed for chopping wood residues. Development of cutting rotate drum was provided in three arrangement steps: *(1)* knives have been replaced by other knives with sharp edge, *(2)* knives have been replaced by knives with sharp edge beside (9 inches) saw disk which have been set on the rotating drum, and *(3)* knives have been replaced by knives with sharp edge beside (14, 12, 9 inches) saw disk mills. The machine was modified from old drum to the new one as shown in Fig. 1 to be more suitable for chopping many types of residues. Each knife is fastened by four bars and rotates with high speed corresponding to a lower speed of feeding drums. The swinging knifes were fitted to the flange by four bars and bolts.

a) *b)*

Fig. 1: a) The old drum under study before modification and b) after modification.

The action of these knifes interacted between themselves actions to help in cut the materials easily, reduce the impact force and prevent the straw around the drum. All disks with different diameters rotate with the main shaft at the same high speed. The maximum force required to cut the wood sample in a direction perpendicular to the growth of the tree fibers Kováč et al. (2014), Kuvik et al. (2017) and Krilek et al. (2015).

Factors under study

The developed machine was evaluated at drum speed, clearance between drum knives, feeding capacity and stages of serrated disk arrangement. According to literature data (Srivastava et al. 2006, CIGR 1999), in reference to this information, machine productivity, power consumption, consumed energy and cutting efficiency were evaluated at each combination of variables.

Tab. 1: Experimental plan for evaluating the machine.

Variables	Levels
Drum speed, rpm	450, 1000, 1200
Clearance between drum knives, cm	0.7, 1.5, 3.00
Feeding capacity, kg h^{-1}	W1 = 300, W2 = 360, W3= 420
stages of serrated disk arrangement	Stage 1, Stage 2 , Stage 3

Finite element modeling using of CAD software

Computer aided design of machine was made by using "SolidWorks" software. Typical dimensions of the machine such as blade size, distance etc. and their 3D models can be easily made in short time. Input commands are provided for cutting tool features such as tool diameter, length of cut etc. Finite element modeling (FEM) was used to conduct a simulation study for stress analysis. A numerical model of chopping machine was created by using three-dimensional software. Deformation under static analysis was found, maximum strain values were obtained. The static results were analyzed and verified by simulation.

The properties of wood residues

The chopping machine was tested with different variety of wood with width in range 4-15 cm, length 18-50 cm and thickness 4-10 cm at 7.3% moisture content on wet base obtained from carpentry workshops. The samples were taken periodically from the machine outlet and placed in polyethylene bags. The samples were even dried at 70°C for 48 h (Nwaigwe et al. 2012) by using electrical oven. Moisture content (MC) was determined according to Eq. 1:

$$MC = m - m_0 / m \quad (\%) \qquad (1)$$

where: MC - moisture content %, m - sample weight before drying, m_0 - weight after drying (g).

Performance evaluation of the developed machine

Evaluation of the hammer mill was performed taking the following measuring parameters:

Machine productivity

El Shal et al. (2010) mentioned that actual capacity of the machine is the actual rate of productivity by the amount of actual time consumed in operation (lost + productive time). Lost time is considered as the time spends in refilling the machine hopper, simple repairs and interruptions. Machine chopper productivity (*P*) was calculated by using Eq. 2 (Mady 1999):

$$P = W \times 3600 / T \qquad (kg \cdot h^{-1}) \qquad (2)$$

where: W - mass of the sample (kg), T - time (s).

Required power and consumed energy

El-Hanfy and Shalby (2009) stated that, the average of cutting length reduced and the distribution percentage of short pieces raised by rising the cutting speeds and overlapping between fixed and rotary knives.

Power consumption *(Pc)* was determined by measuring the volume of diesel fuel required and refueling the machine tank after finishing the operation time. The power was calculated by using Eq. 3. The consumed energy (CE) is power per unit productivity; it was calculated by the using Eq. 4. (El-Fatih et al. 2010):

$$Pc = FC \times \rho f \times LCV \times 427 \times \eta_m \times \eta_{th} / 3600 \times 75 \times 1.36 \qquad (kW) \qquad (3)$$

$$CE = Pc / P \qquad (kW.h.kg^{-1}) \qquad (4)$$

where: *FC* – fuel consumption ($l \cdot h^{-1}$), *ρf* – fuel density (Diesel 0,85 $kg \cdot l^{-1}$), *LCV* – lower calorific value of fuel (11000 $kcal \cdot kg^{-1}$), thermo- mechanical equivalent (427 $kg \cdot m \cdot kcal^{-1}$), η_m – engine mechanical efficiency (85% Diesel engine), η_{th} – engine thermal efficiency (25% diesel engine).

Cutting efficiency

Nwaigwe et al. (2012) noted that, the efficiency of the modified chopping materials mill is given by using Eq. 5:

$$Em = (\text{Amount passing sieve} / \text{Total weight of sample}) \times 100 \qquad (5)$$

RESULTS AND DISCUSSION

Finite element modeling

The applied mechanism here is impact loading where the time of application of force is less than the natural frequency of vibration of the body. Since the hammers are rotating at high speed, the time for which the particles come in contact with the hammers is very small, so here impact loading is applied. Swinging instead of hammers was used to avoid the hammers from getting stocked in case a hammer comes in contact with a material it cannot break at first impact.

A solid model is the complete type of geometric model used in CAD systems as sown at (Figs. 2 and 3). The shaft is considered to be subjected to torsion and bending. The model is considered for the horizontal shaft impact chopping to find out the relation between the feed, the crusher and the output parameters. Attrition method has the material scrubbed between the hammers and the screen bars. Attrition consumes more power and causes heavier wear on hammers and screen bars. Many studies have been investigated on elastic constants of wood through using different testing methods (Aira et al. 2014), non-destructive method (Tomazello et al. 2008, Xu et al. 2020), and resonant beam technique (Gerhard et al. 2020).

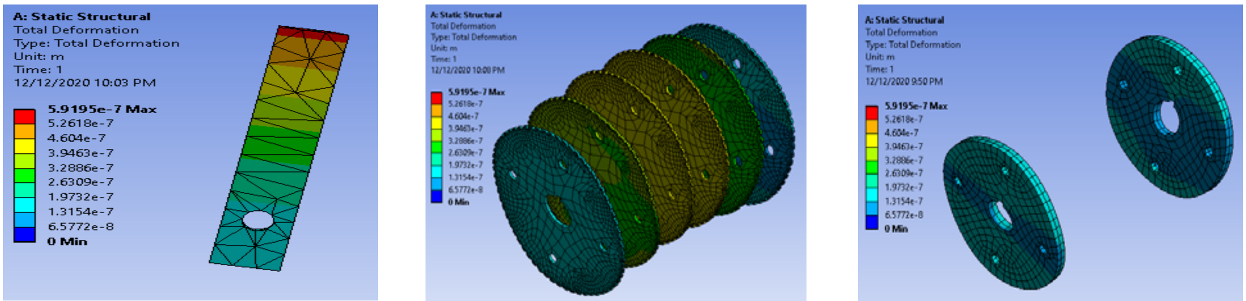

Fig. 2: Model analysis of the knife, disk and flange deformations in Ansys Pro.

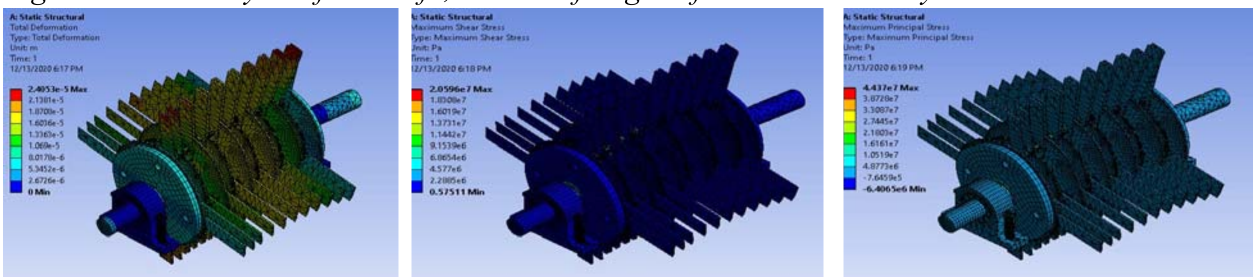

Fig. 3: Model analysis of the drum deformation, shear stress and principal stress in Ansys Pro.

Evaluation of the productivity with wood residues

The data in Fig. 4 shows that the cutting productivity raised with rising the cutting drum speed and reducing the clearance between flail knives (0.7, 1.5 and 3 cm).

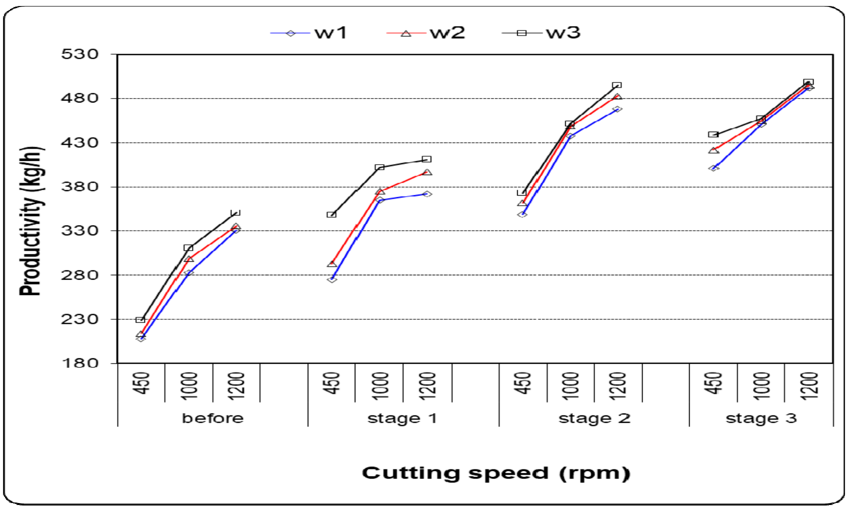

Fig. 4: The relationship between cutting drum speed and productivity at three levels of feeding capacity (w1,w2 and w3) for wood residues at 7.2% moisture content.

Power requirement

The data in Fig. 5 shows that the power requirements reduced with rising cutting drum speed while the power requirements reduced with reducing the clearance between flail knives (0.7, 1.5 and 3 cm). The results show that the power consumption and energy requirement for cutting different residues was raised with rising drum speed, feed rate and moisture content but the power consumption and energy requirement were reduced by rising the concave clearance, the results agree with Arfa (2007).

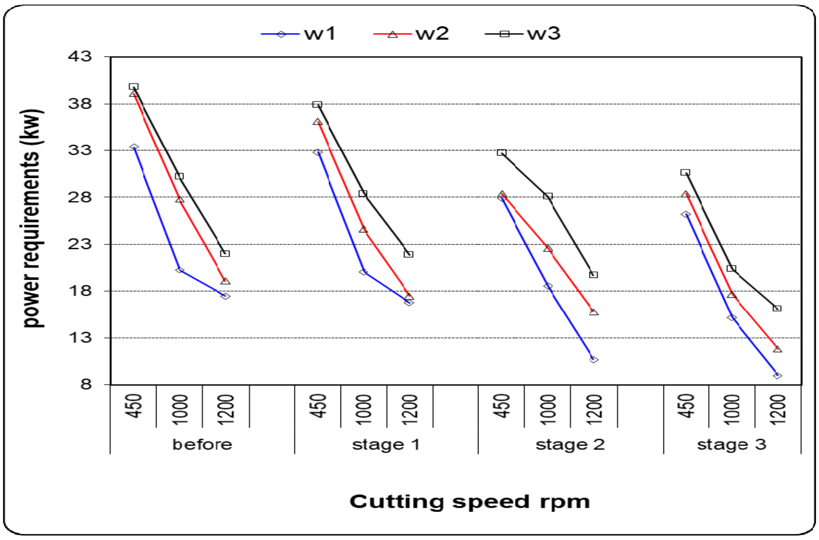

Fig. 5: The relationship between cutting drum; speed and power requirements at three levels of feeding capacity (w1,w2 and w3) for wood residues at 7.2% moisture content.

Energy consumption

The data in Fig 6 show that the energy consumption reduced with rising cutting drum speed and with reducing the clearance between flail knives (0.7, 1.5 and 3 cm).

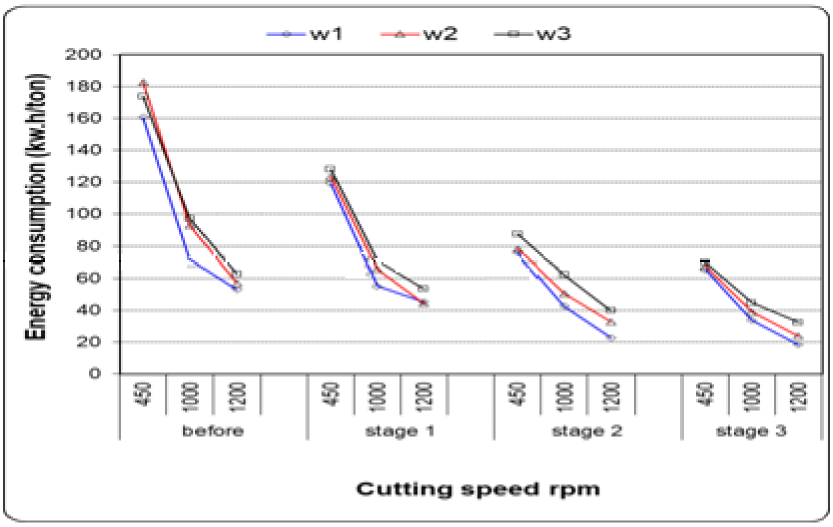

Fig. 6: The relationship between cutting drum speed and energy consumption at three levels of feeding capacity (w1,w2 and w3) for wood residues at 7.2% moisture content.

Cutting efficiency

The data in Fig. 7 show that the cutting efficiency raised with rising the cutting drum speed while the cutting efficiency raised with reducing the clearance between flail knives (0.7, 1.5 and 3 cm). It was possible to separately observe the amount of cutting force for cutting knifes thickness Kováč et al. (2014), Kuvik et al. (2017) and Krilek et al. (2015).

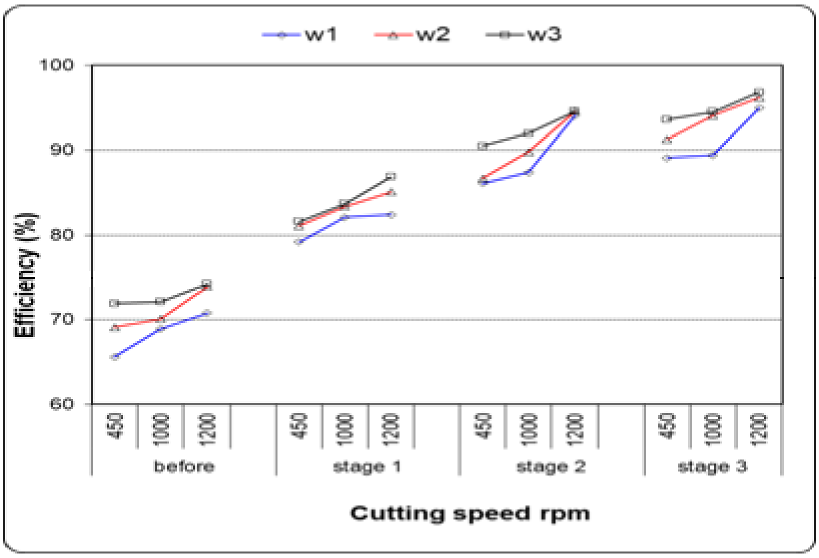

Fig. 7: The relationship between cutting drum speed and efficiency at three levels of feeding capacity (w1,w2 and w3) for wood residues at 7.2% moisture content.

CONCLUSIONS

From the above mentioned study, it can recommend that: *(1)* The addition of the serrated disc mills and the distance between reduce sharp flail knives themselves support the process of cutting force. *(2)* Using the modified (serrated) saw disk mill and flail knives reduced the energy requirement for chopping and raised fine degree of the chopped materials. *(3)* Reducing the serrated disk arrangement clearance between drum knives (0.7, 1.5 and 3 cm) solve the clogging problem and reduced the energy requirement for chopping and raised fine degree of the chopped materials.

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