



## Computer Software Application in the Development of Agricultural Machine Design

B. G. Jahun<sup>1</sup>, D. D. Usman<sup>1</sup>, D. Ahmad<sup>2</sup>, F. A. Astapawa<sup>3</sup>

<sup>1</sup>Department of Agricultural and Bioresource Engineering,  
Abubakar Tafawa Balewa University, PMB 0248, Bauchi State Nigeria,

<sup>2</sup>Department of Biological and Agricultural Engineering,  
Universiti Putra Malaysia 43400 Serdang,  
Selangor/Darul Ehsan Malaysia,

<sup>3</sup>Department of Agricultural and Environmental Engineering,  
Modibbo Adama University of Technology, Yola  
Adamawa State Nigeria

### ABSTRACT

Traditionally, artisans carried out designing of agricultural tractors and implement, which is laborious, time-consuming and less efficient. Currently, computer and software application technologies are developing rapidly in the tractor and implement design applications as it is in many areas. One of these is SolidWorks, a three-dimensional solid modelling design program that is most commonly used and open to development in the design of agricultural tractors, implement and analysis in the windows applications. In this work, the design of four tractor-mounted mulcher blades models was performed in 2D and 3D and simulated using the general features of the software. The results from the simulation show that Blade with 120° lifting angle has the lowest stress and deformation whilst the Blade with 150° lifting angle has the highest when compared with the yield point of the material (62.04 MPa). It is recommended that Blade with 120° lifting angle for tractor-mounted mulcher should be used for mulching oil palm fronds.

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### INTRODUCTION

In the early days, the manufacturers of agricultural tractors and implement parts, artisans that learned the trade as indentured apprentices carried out fittings and assembly. Each part tailored to fit its mating parts. Consequently, artisan needed to be an expert in all the various aspects of manufacture and assembly, and training a new artisan was a long and expensive task. The scale of production was often limited by the availability of trained artisans rather than by the demand for the product. This problem was compounded by

the reluctance of the craft guilds to increase the number of workers in a particular craft (Mohanty, 2012). Design engineers require specialized software, tools, and applications to research and develop ideas for new products and their associated systems. It is required to create blueprints and schematics for structures, systems, machines, and equipment and work collaboratively with other engineers, drafters, and team members, and to be able to work productively and efficiently, Matani and Bhisnurkar (2015).



To succeed in competitive global market, manufacturers of agricultural machinery and heavy equipment had to compress design cycles and accelerate product time-to-market, while simultaneously controlling costs, increasing product complexity, and delivering consistently high levels of quality. Meeting these challenges requires, to modernize the product development systems and implement an integrated 3D design platform, to realize the benefits of automation and eliminate the unnecessary tasks, costs, and delays associated with traditional, non-integrated approaches to machine design. By taking advantage of a proven integrated 3D environment such as SOLIDWORKS® design to manufacturing ecosystem, design, validate, and produce higher quality, better-performing machines in shorter amounts of time and at a lower cost would be achieved Kamboj (2011).

Computer-integrated applications have advantages over conventional manufacturing applications (Çelik and Akıncı.2012). Computer-aided design (CAD) as a critical module of a computer integrated manufacturing (CIM) system is an interaction of human and machine working together to optimize design and manufacture activities of products in Product Development Environment (PDE). Generally, it is used to design product by the introduction of computer technology. Engineers and Architects have access to 3D Computer-Aided Design (CAD) tools, which not only help build a virtual prototype but also simulate the structural integrity of their model (Fritscher and Pigneur. 2014) and reduces engineering costs for companies and results in products getting to market much faster. A lot of CAD software are available in the market such as Auto CAD, PRO-E, Solid Edge, SolidWorks etc. Different software has different functionality and used by specific fields for specific purposes.

Some CAD software not only generates sketches and 3D models of the machines but also includes simulation and structural analysis of the model. Solid Edge, CATIA and SolidWorks are software that provides all features desired to develop and analyze the machine stresses and forces even before actual making of the physical model Gadus (2000).

Some researchers used CAD software for the design of a solid model of their machines such as Singh (2007) developed a wheel hand hoe mounted on fertilizer broadcaster CAD model using computer-aided software called PRO-E and different parameters such as soil thrust is checked. Lye and Salleh (1997) investigated a two dimensional model of the agricultural plough to compute the effect of different shapes (C-blade, L-blade and I-blade) of plough blade and stress distribution by using “Micro Field Finite Element Package” and concluded that L-blade created the highest displacements and stresses over the blade compared to the C-blade and I-blade. Topakci *et al.* (2010) worked on “variations of torque and specific tilling energy for different rotary blades”. The torque characteristics and the specific tilling energies of three commonly used rotary blades that are the Japanese C-shaped blade, the European C-shaped blade and the European L-shaped blade were design, simulated and analyzed to find a suitable rotary blade for seedbed preparation using SolidWorks. The experiment was done in a laboratory soil bin at forwarding speeds of 0.034, and 0.069 m/s, and rotational speeds of 150, 218, 278 and 348 r/min (or 3.30, 4.79, 6.11 and 7.65 m/s) in sandy loam and clay soils. They reported that the suitable blade for seedbed preparation was the European L-shaped blade at a forward speed of 0.069 m/s and rotational speeds of 4.79 m/s respectively. Mandal *et al.* (2013) researched on Design and Development of rotavator blade: Interrogation of CAD



method. They reported that blades interact with soil in a different way than normal ploughs, which are subject to impact and high friction that creates unbalancing and non-uniform forces, which result in blade wear. Therefore, it is necessary to design and develop a suitable blade so that self-life is enhanced.

To meet the different needs arising in the agricultural design, it has become imperative to design and develop various types and functional agricultural tools and machines in a short time using software application packages that are highly precise, qualitative and low cost. Computer and software technologies that step in the direction of these demands, especially in the design and manufacture of complex multifunction systems offer great benefits in terms of cost, time and labour savings (Chiu and Chu, 2012). Application of technology systems as seen in many sectors including agriculture and food is apparent. Traditionally, the agricultural industry has been solely dependent on human labour with limited application of mechanical equipment and machines. The applications of advanced technology such as embedded computing, robotics, wireless technology, GPS/GIS (Geographical Positioning System/Geographical Information System) and DBMS (Database Management System) software are seen to be recent developments (Suprem *et al.*, 2013). This paper presents the applications of Computer software technology systems in agricultural and food in the design of machinery parts and implement using modern engineering tools such as Solid Works concerning tractor-mounted mulcher blades.

## MATERIALS AND METHODS

SolidWorks software not only provides all features desired to design and develop the blades but also helps to analyze the stresses and deformations on different blades even before the actual fabrication of physical blade models were made. SolidWorks software was used to design the 2D and 3D models based on typical dimensions of the blades.

### **Description of Tractor Mounted Mulcher Machine and Blade Configurations**

Tractor Mounted Mulcher is one of the newly mulching implements. Mounted to a tractor through the three-point hitch and driven by the tractor power-take-off (PTO) shaft. Operational depth control by a hydraulically operated lever. It cuts the oil palm fronds, stem and mixes it with the soil. It turns over the mulched soil so that stalks and other green material of oil palm fronds are covered or buried and hence conserved for nutrients; destroy the inhabitants of rodents, insects and diseases.

Primarily, it is of two blades with lifting angle  $0^\circ$  opposite to each other, attached on two blade carriers fixed to a rotor. During mulching operations, various factors affect their energy requirements. These factors can include soil conditions, operational conditions and blade configuration. Only the cutting edges of the mulching blades are in contact with the soil. The blades are so designed that can be used in a loamy soil that keeps them sharp. The efficiency of the blade is determined largely by the condition of the soils. If left dull or distorted when striking the solid obstacles in the ground and are not sharpened, it requires double the power to drive, the quality of work would be poor and the blade will wear much more quickly. Trouble also arise with clogging under the shield/side of the blade carrier.

Blades are the main parts of tractor-mounted mulcher implement

(Figure11), which directly engaged with the soil to cut and mix oil palm fronds with the soil during mulching operation. The blade components work under varied forces due to power, vibration, torque, impact effect of soil parts (stones and stumps). The

manufacturing and development errors can be minimized by its components design analysis and field performance evaluation of the developed different blade lifting angles.



**Figure1:** A Vertically Operated Tractor Mounted Mulcher with Blades

The geometry of mulcher blades is measured as a significant factor in their design since both the figure of the blade-lifting angle and the length of the mulcher blade facilitate cutting. The contact between the blade and the soil moves slowly from the blade carrier at the periphery of the drum of the shaft to the blade length. The blade lifting angle cuts the windrow/scattered oil palm fronds at the boundary between the blade edge and the blade lifting angle. While mulching oil

palm fronds, the oil palm fronds are incorporated into the soil.

#### ***Design Process of Tractor Mounted Mulcher Blades Using SolidWorks***

The development of tractor mounted mulcher blade was done by modifying blade lifting angle/geometry, reducing its weight and improving field performance to a high degree of mulching efficiency. The dimension details were obtained from real component and the design modification was done by changing geometry and lifting angles as given in .

Table 1. All the dimensions of the mulcher blades are in millimetres.



**Table 1:** Modified Dimension Details of Four Tractor Mounted Mulcher Blades

Blade Types	Width Mm	Thickness mm	Mass, kg	Volume m <sup>3</sup>	Weight N	Length mm	Depth mm	Density Kg/m <sup>3</sup>
0°	17	5	5.82	0.000757835	57.19	210	236	7700
60°	17	5	3.29	0.000427459	32.26	210	181.87	7700
120°	17	5	3.54	0.000459906	34.70	210.03	231.90	7700
150°	17	5	5.54	0.000719409	54.29	210	236	7700

To begin the process of creating 3D models in Solid Works, the sketches from the concept section of the blades were developed using a crude estimate of a scaled-down set of dimensions for the different designs. These dimensions were applied to each design so that each blade had the same thickness, length, and circumference, thus making it possible to determine which connection would be the strongest and most reliable design.

Three different blades were developed (with different lifting angles (60°,

120°, and 150°)) with an original blade (0°) as control and developed with CAD methods as shown in Figure **Error! Reference source not found.** and analyzed by SolidWorks software. Geometrical parameters were used at the initial stage as a basis for 3D modelling related to commercially available mulcher tools using 3D CAD software.

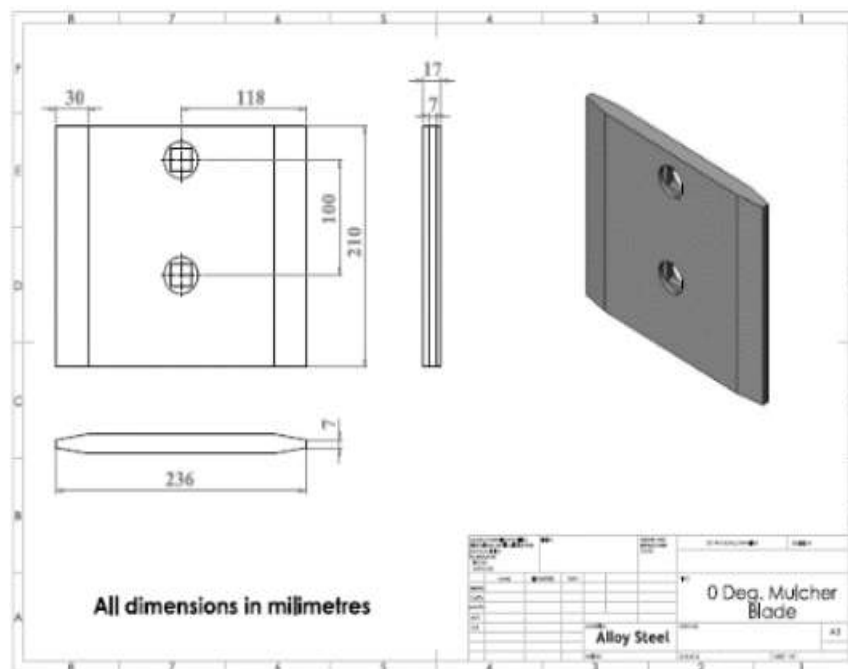
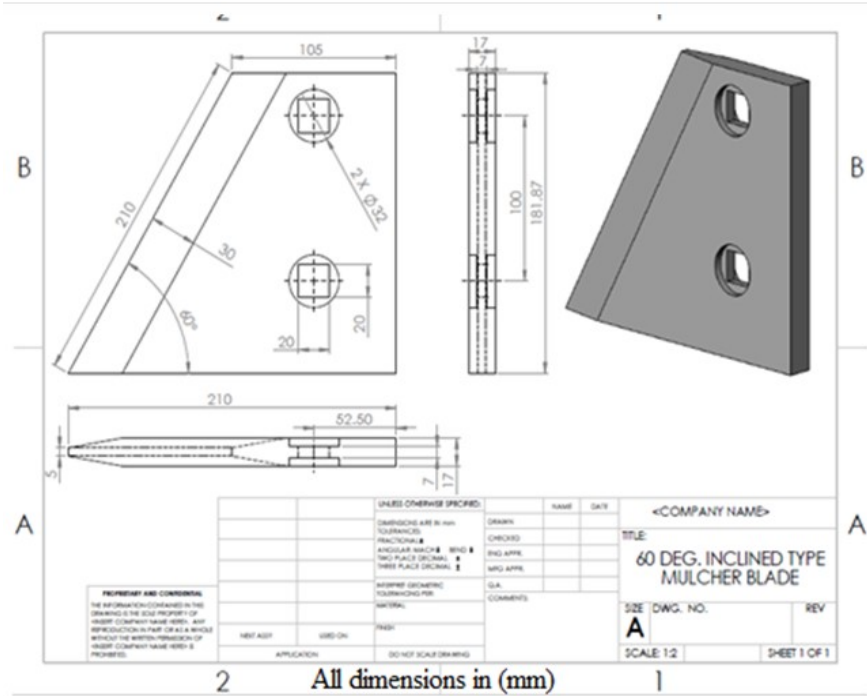
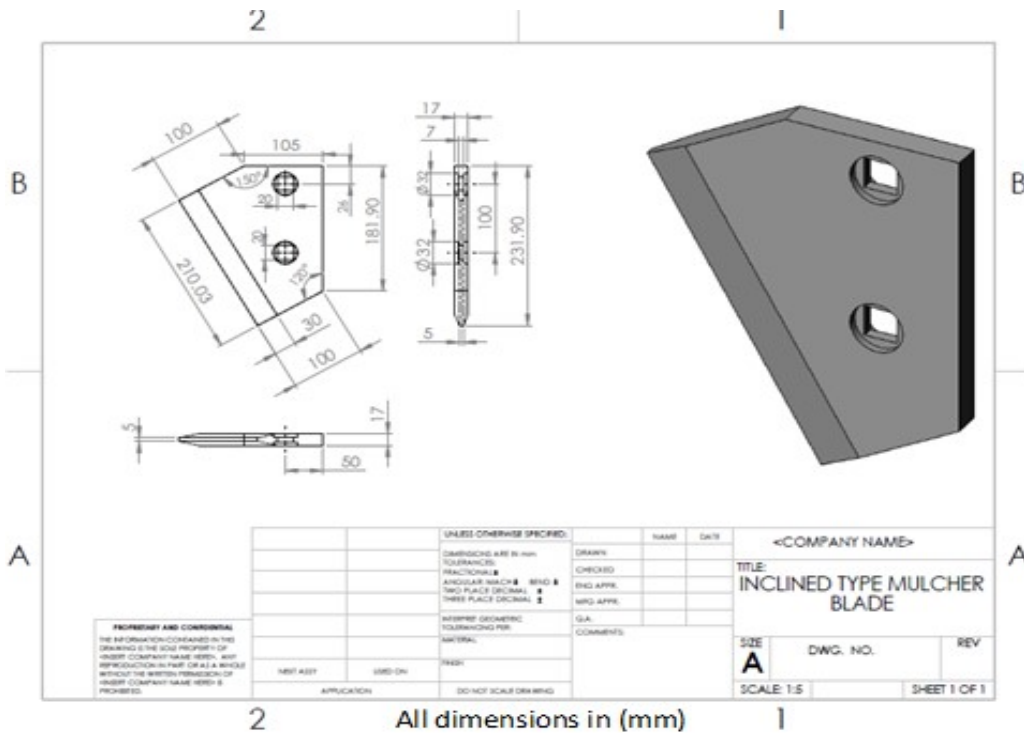
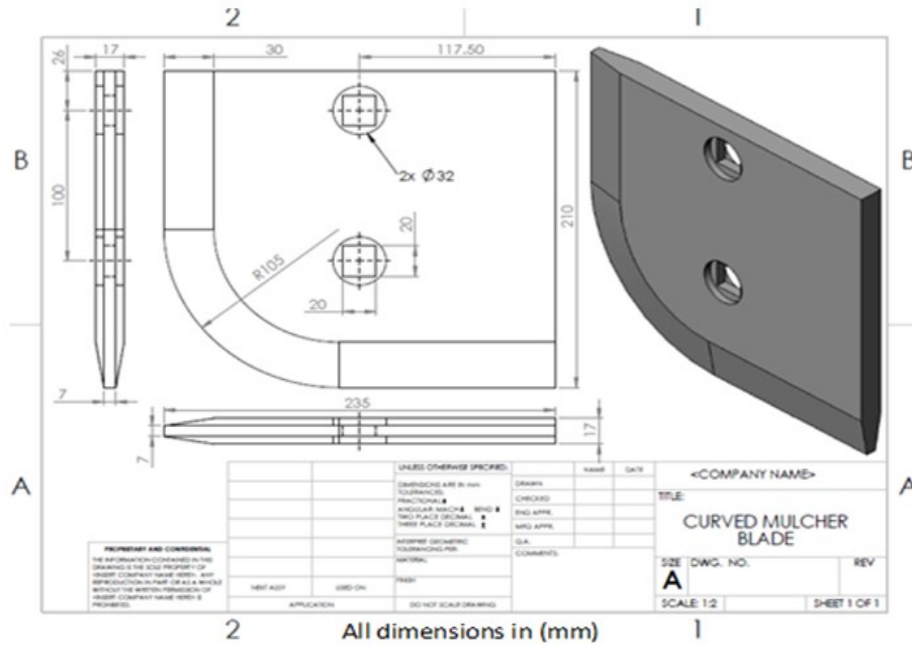


Figure 2: Orthographic and 3D Model Mulcher Blades with 0° and 60° Lifting Angles (Original Mulcher Blade from Howard)



**Figure3:** Orthographic and 3D Model Mulcher Blades with 120° and 150° Lifting Angles

The 2-D engineering drawings were generated from corresponding blades in the drawing module, and automatic dimensioning was done in each drawing. Noted that 3-D models and 2-D engineering drawings were related to each other, namely any modification of dimensions made in 3-D part and assembly module would be reflected in drawing module and vice versa. Some necessary annotations such as geometric tolerance, surface finish symbol and BOM (Bill of Material), etc. were inserted into drawings as these were required for manufacture. Completed engineering drawings were saved in the default file format of SolidWorks and DWG format which is recognizable by AutoCAD. 2-D projection drawing of the whole machine as shown in Figures 2 and 3 above as reported by Xinglong, 2011.

By using FEM for tractor mounted mulcher blade structure analysis, it is possible to generate values of stresses and displacements for both situations which allowed the choice of suitable design for structural components of a tractor-mounted mulcher blade. The critical blades components were validated by FEM analysis package (SolidWorks, 2013). It predicted the real condition of blade components in the operation. The method eliminates the traditional way of validating the design of components for a specific application by manufacturing and testing on a prototype, which is expensive and time-consuming.

FEM is based on the assumption that the displacement of each element may vary inside the body analyzed. To do a complete discretization, all loads applied to the structure must be condensed into a set of equivalent discrete nodal forces according to Equation (1):

$$F = M\ddot{u} + C\dot{u} + Ku$$

(1)

Where;

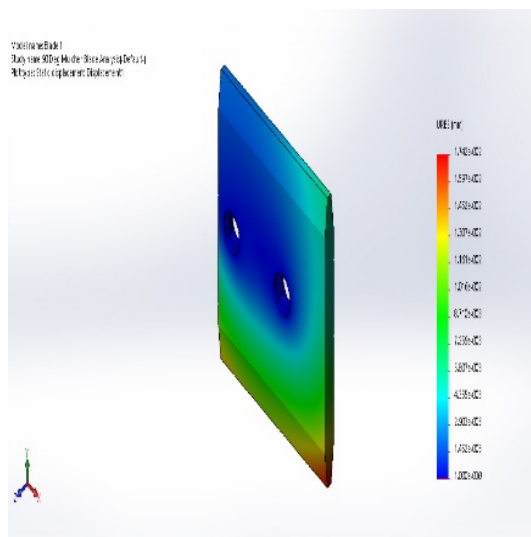
$F$  is a nodal load factor

$M\ddot{u}$  is the inertial load vector

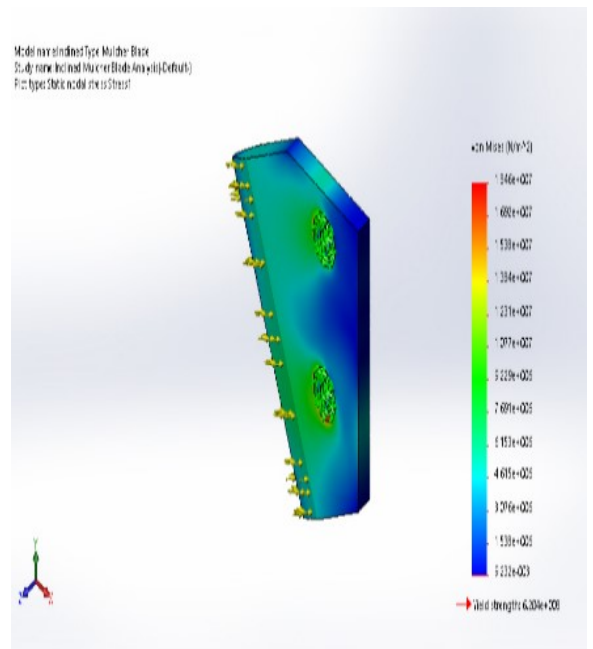
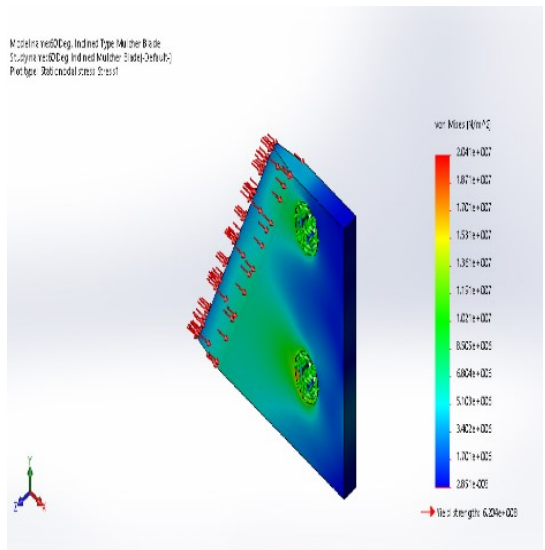
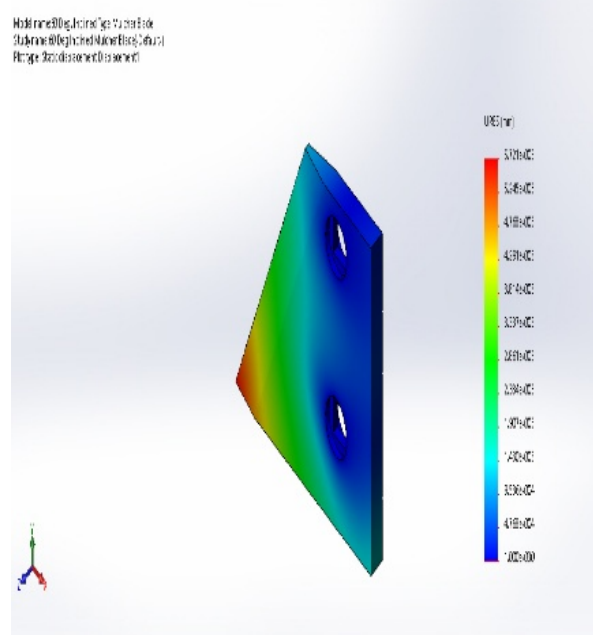
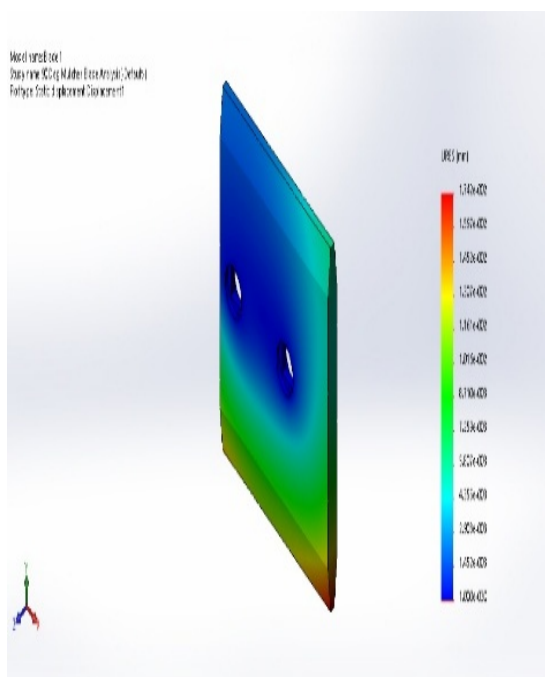
$C\dot{u}$  is the damping load and,

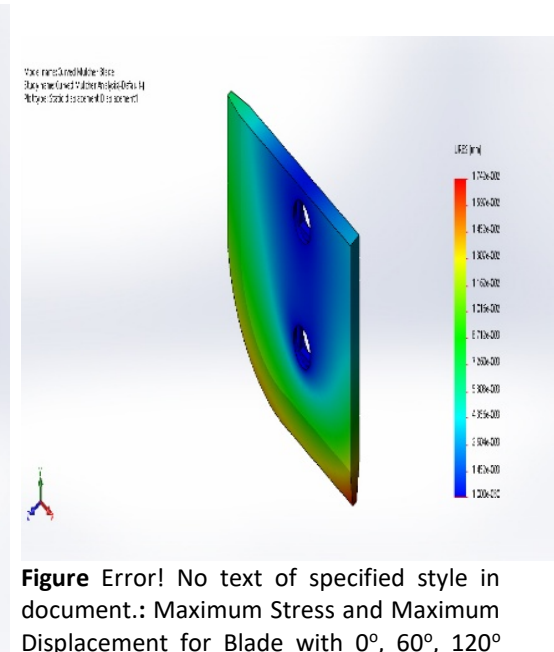
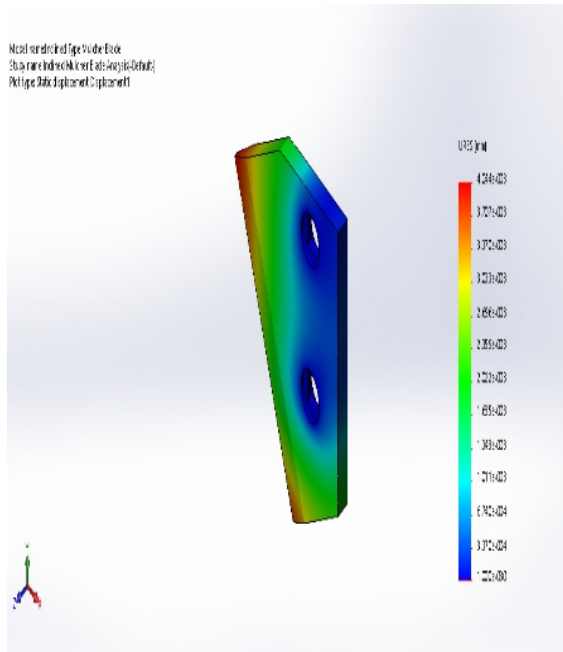
$Ku$  is the elastic load vector.

Based on the loads acting on the tractor mounted mulcher blade as input data, it is possible to predict the structure displacements helped by mathematical modelling such as FEM. Also helped by FEM and material properties information, is possible to predict the Von Mises (VM) stress, for ductile materials, which is associated to the distortion energy of components (Evandroet *et al.*, 2014).

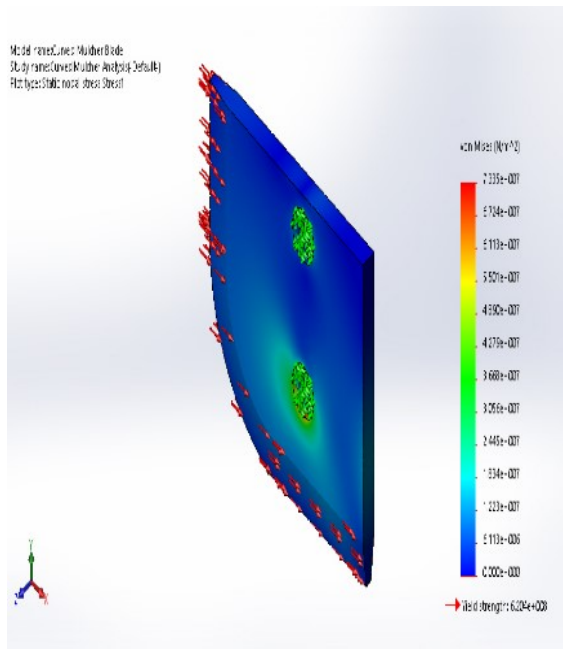








**Figure** Error! No text of specified style in document.: Maximum Stress and Maximum Displacement for Blade with 0°, 60°, 120° and 150°Lifting Angles



In general, while using FEM technique for failure analysis, a finite element routine was first used to calculate the static and dynamic displacement and stresses under the maximum compression and tension loading, which was then used for critical points evaluation, Mahesh *et al.* (2011). The loading of the specimen was carried out in different modes: by maintaining tensile force or axial displacement constant and increasing torque or angle of twist and maintaining torque or angle of twist constant and increasing load or axial displacement. A finite element solution of the problem was obtained to gain further insight into the effects of the loading modes Zarrouget *al.* (2003).

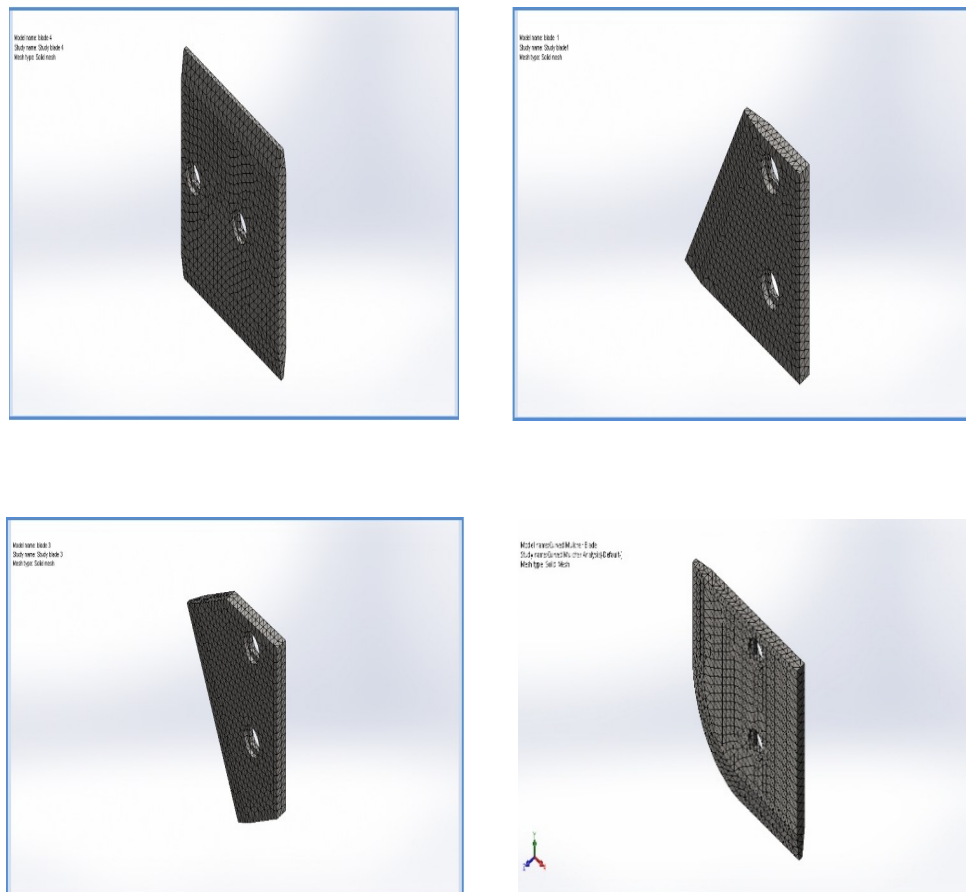
Von Mises stress was used in determining whether an isotropic and ductile metal will yield when subjected to a complex loading condition. This is accomplished by calculating the Von Mises stress and comparing it to the materials

yield stress, which constitutes the Von Mises Yield criterion (Brammah *et al.*, 2017).

### **Computational Mesh of Tractor Mounted Mulcher Blades**

To generate the computational mesh, relevant geometries of the computational domain were first defined in the computer-aided design (CAD) environment, SolidWorks. The CAD model was cleaned (e.g. checked if there were any geometrical errors) in ANSYS ICEM meshing software before it was used for meshing. After the mesh was generated in ICEM as shown in Figure 5, a more detailed analysis of the mesh quality was performed. ICEM

allows quality check, smoothing and refinement based on different criteria (e.g. orthogonality, aspect ratio, skewness). The mesh quality was carefully examined and improved through quality criteria (e.g. minimum orthogonality = 0.3, maximum aspect ratio = 10 and maximum skewness = 0.25), smoothing and refinement features available in ICEM as recommended in ICEM meshing guidelines (ANSYS, 2016). These are essential to ensure good quality mesh not to hinder numerical convergence. To improve the mesh quality, at least ten prismatic layers were generated on all walls and blades in an attempt to capture the whole features of the blade boundary layer.



**Figure 5:** Analysis of Meshing Density of Blades with 0°, 60°, 120° and 150° Lifting Angles



## DISCUSSION OF RESULTS

Material properties used in the analysis are presented in Table 2. Figure 4 shows the results of the analysis in finite element model for the Blade with 0°, 60°, 120° and 150° lifting angles respectively. The results were documented and the comparison presented in Table 3. The results showed that maximum stress was on the Blade with 150° lifting angle while the

lowest was on the Blade with 120° lifting angle. At the same time, maximum deformation was achieved for the Blade with 150° lifting angle and lowest for the Blade with 120° lifting angle. The Blade with 0° lifting angle also experienced deformation near to the deformation of Blade with 150° lifting angle, but stress value was minimum for the Blade with 120° lifting angle.

**Table 2:** Blade Material Properties

Properties	Values
Yield Strength	$6.20 \times 10^2$ MN
Tensile Strength	$7.24 \times 10^2$ MN
Elastic Modulus	$2.1 \times 10^{11}$ N/m <sup>2</sup>
Poisson's ratio	0.28
Mass Density	7700kg/m <sup>2</sup>
Shear Modulus	$7.9 \times 10^{10}$ N/m <sup>2</sup>
Thermal Expansion	$1.3 \times 10^{-5}$ /Kelvin

**Table 3:** Mesh Convergence Test Analysis for Tractor Mounted Mulcher Blades

Types of Blades	Maximum Elements	Convergence	Maximum Stress (MPa)	Maximum Displacement (mm)
0°	302,869		44.85	0.00175085
60°	177,041		19.9	0.00573563
120°	197,861		18.92	0.00405284
150°	292,180		74.29	0.00175376

The maximum tensile stress and deformation were 74.29 MPa and 0.00175376 mm respectively. From the results, the tensile stress obtained was above the yield strength of the material used. The stresses on the blade with 150° lifting angle top section were unbearably maximum, whilst the stresses on the whole body of the blade with 120° was at minimal values of 18.92 MPa. According to the Maximum Yield Stress Theory, if the Von-Mises stress on the blade is lower than the

yield strength of the material used for its construction, then the blade will be safe for that operational condition. Since the Von-Mises stress of the designed tractor-mounted mulcher of Blade with 120° lifting angle is lower than the yield strength of the material used, it is safe for the above operating condition.

## CONCLUSION

Considering the traditional methods of designing agricultural machine



which is laborious and time-consuming, SolidWorks was applied to accomplish blades design, interference detection and generation of 2-D engineering drawings with ease of reference. Results showed that the design was reasonable and feasible. The designed blades were models for subsequent simulation and analysis. The study provides theoretical foundations and methodological references for the application of SolidWorks technology on the development of new tractor mounted mulcher blades.

#### ACKNOWLEDGEMENTS

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