Journal of Agricultural Engineering and Technology (JAET)
JAET - CIGR Section VI Special Issue:
Innovation & Technologies for Sustainable Agricultural Production & Food Sufficiency
JAET, June, 2019. Vol. 24(2):53-63
Published by the Nigerian Institution of Agricultural Engineers (NIAE).

Print ISSN: 014-2222, Electronic ISSN: 2651-558X
www.jaet.com.ng

TRACTOR MOUNTED MULCHER BLADE STRUCTURAL ANALYSIS USING FINITE ELEMENT METHOD

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ABSTRACT
The maximum stress and deformation due to impact in the mulcher blade during field operation is the major concerns in the design considerations. The blade works under varied forces due to power, vibration, and torque, impact effect of soil parts (stones and stumps). To determine the impact-induced maximum stress and deformation, Solid Works software was used for both design of four 3D Model blades and Finite Element Analysis (FEA). FEA was carried out to investigate the failure of the four designed blades under worst case scenario, and tested at same conditions. Simulations were run at six treatment levels on blades with 0°, 60°, 120° and 150° lifting angles. Results were compared against the average measured stress and deformation. From the simulation effects, maximum stress and deformation on the blade with 120° lifting angle were 18.95 MPa and 0.0041 mm respectively. All stress and deformation values were within the acceptable limit for the design intent and material specifications of the mulcher blade. Maximum stress on the blade with 150° lifting angle were 74.29 MPa and 0.0175376 mm accordingly. The stress distributions were above the yield stress (62.04 MPa) of the specified blade material, the blade was the worst in terms of failure due to fatigue.

Key words: Mulcher Blade, Stress, Deformation, Finite element method, Nigeria.

1 INTRODUCTION

The oil produced from one tree constitutes only 10% of the total biomass, leaving 90% available during oil palm tree felling for replanting or further land development activities (Wicke et al., 2011). Currently, these felled palm trees are being shredded and left in the field for mulching/soil regeneration purposes. Tractor mounted mulcher machine is used in mulching crop residues in oil palm plantation field. It comprises of 0° blade lifting angle mounted on three point linkages and driven by the tractor power-take-off (PTO) shaft. During mulching operations various factors affect its energy requirements. These factors can include soil conditions, operational conditions and blade geometry. It has a capacity for cutting of oil palm fronds, mixing topsoil and preparing oil palm fields prior to replanting directly. It has more mulching capacity than forestry mulchers (Abdullah and Sulaiman, 2013). The blades work under forces because of power, torque, vibration and impact effect of soil parts after reaching higher side. Blades have to be reliable in field performance against operating forces. Predicting stress distributions and deformation is important for the designers, manufacturers and end users (Shinde et al., 2011).

Improvement in computers and computational techniques has led to the development of a new generation of highly efficient programs for simulating real situations. Numerical techniques, especially finite element method (FEM), help to analyze the soil–blade interaction with the development of a suitable constitutive (stress-deformation) relation for specific working condition. FEM predicts information about the failure zone, stress and deformation, acting forces on blades for agricultural equipment without limitation on the geometry of blades (Armin et al., 2014).

The maximum stress and deformation due to impact in the mulcher blade during field operation is the major concern in the design considerations. It is obvious that the toughness of material is connected to its ductility, ultimate strength and the capacity of structure to endure an impact load which relies upon toughness of material used (Shigley, 2011).

Estimation of maximum stress and deformation of mulching blade geometry effects on soil physical properties is important. Unless the correct blade geometry combination is chosen for mulching implement, the long term effects of soil mulching by tractor mounted mulcher may result in poor soil structure. Incorrect blade geometry may also result in unnecessary waste in machinery input energy (Masiyandima, 1995).

The FE model with the finest mesh generated the most accurate results with dependent on factors such as geometry, type and size of mesh element and loading condition. Effect of parameters such as geometry and size of mulcher blades were considered (Shigley, 2011).

The objectives of this research were to study the effects of blade geometry (operating lifting angles) on soil forces and compare the results using the finite element method for four different blade lifting angles.

2. Materials and Methods

Several meshing patterns were performed to verify convergence. Large number of equilibrium iterations were required for convergence, the calculations were mostly long (normally lasting numerous hours on a computer with Intel core i3 4 GHz processor and 3.2 GB of RAM). Thus for computational efficiency and to make a balance between computational effort and accuracy, each model was meshed with higher density near the contact areas, and only the models that can be considered converged are shown in this study.

Three different blades were developed (with different lifting angles of 60°, 120°, and 150°) with the original blade (0°) as control and developed with CAD methods (Figures 1 and 2) and analyzed by 3D modeling. Geometrical parameters were used at initial stage as a basis for 3D modeling which were related to commercially available mulcher tools using 3D CAD software.

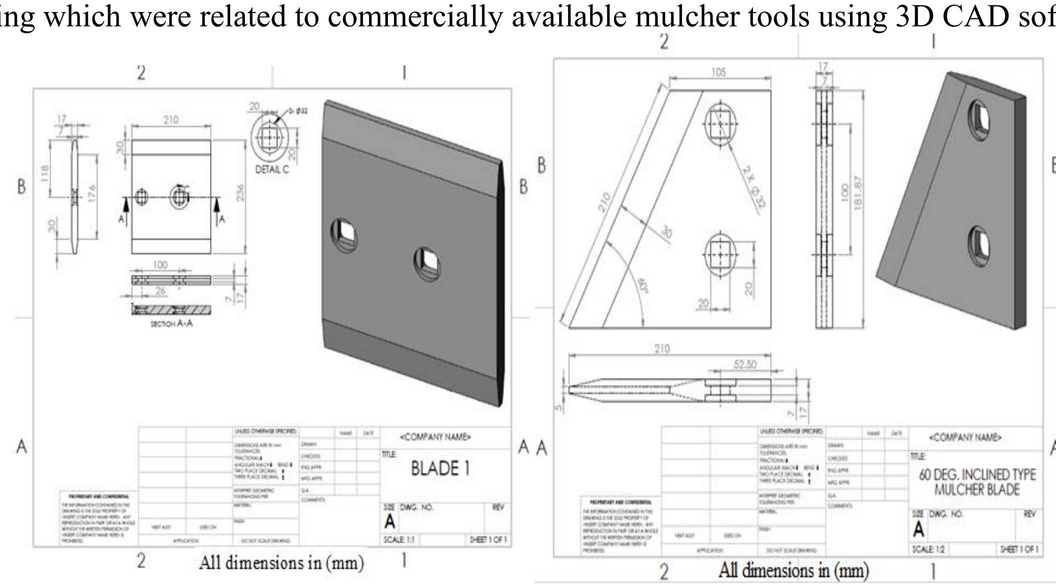

Figure 1: Orthographic and 3D Model Mulcher Blade with 0° (Original Mulcher Blade from Howard) and 60° Lifting Angle

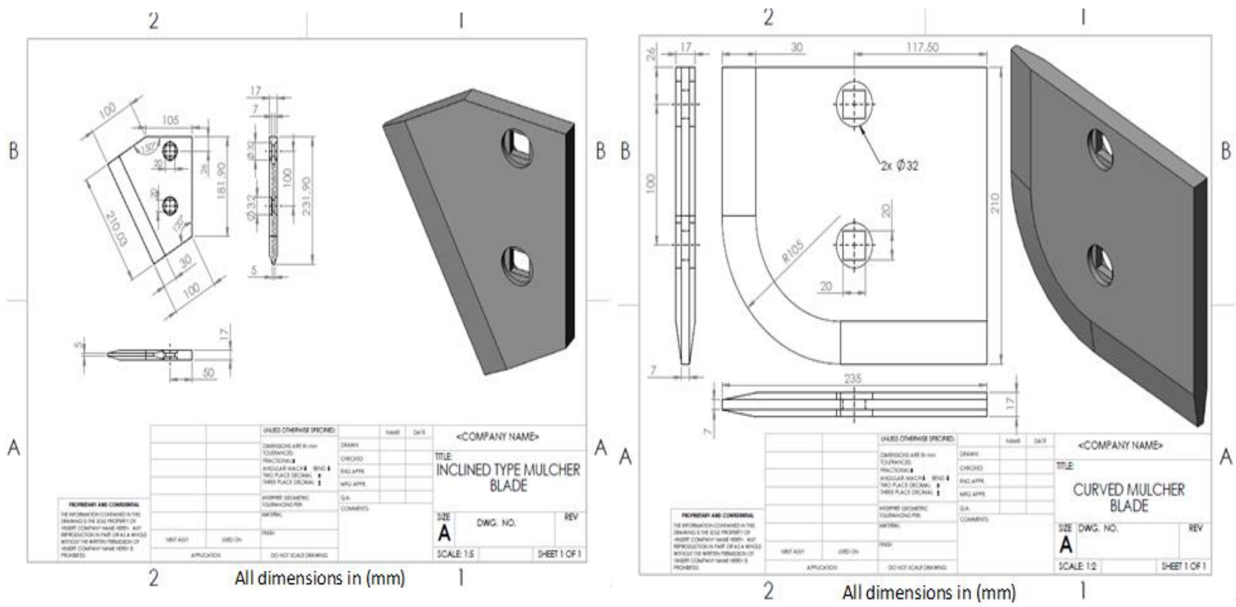

Figure 2: Orthographic and 3D Model Mulcher Blade with 120° and 150° Lifting Angle

The mulcher blade properties (Steel) were obtained from the database of Howard Company production system. The material properties (two steel sizes AISI 1040 and AISI 1148) were used for the design and production of three mulcher blades and soil properties were considered based on the blade material properties as shown in Table 1. The Steel material used is available in Malaysia and easy to access and cheap. The structural analysis was carried out to check the stress distribution and displacement on the new blades and the original blade from the Howard Company. To compare with the original blade, both original and new blades were modeled and analyzed using FEM. The blades were simulated before field testing and black cotton soil was considered as a reference soil with shear strength of 1350 x 103 N/m^2.

Table 1: Properties of steel materials for analysis

Material Properties	Values
Yield Strength	6.204x108 N/m^2
Tensile Strength	7.23826x108 N/m^2
Elastic Modulus	2.1x1011 N/m^2
Poison's ratio	0.28
Mass density	7700 kg/m^3
Shear Modulus	7.9x1010 N/m^2
Thermal Expansion	1.3x10-5/Kelvin

A three-dimensional based finite element model was analyzed in Solid Works 2014 SP5 software to assess the effect of mesh density on material property and the resulting influence on the predicted stress distribution. The same loading conditions were used in all models.

2.1 Boundary and Loading Conditions

Fixed support constraints (boundary conditions) were applied into the holes located on the meshed geometric models as represented the point of attachment to the blade carrier. Loads (forces) were applied to the cutting edges of the blades to investigate the stresses and

deformation and its effect on the blade material. These loads were derived from using the Mckyes and Ali's model for calculating soil forces Amin et al., 2014. Mckyes and Ali's model was adopted in the determination of anticipated soil reaction forces on the blades.
The highest stress/deformation level was observed in the element which was at the tip of the opening and was of a particular interest during the whole simulation. At the beginning all bonding forces were active and this element (to be referred to as the tip element) is adjacent to the tip of blade. As the blade started to move, stresses went through the elastic phase until the solid line representing the yielding condition was reached.

Simulations were run at the six treatment levels from the laboratory test on four design tractor mounted mulcher blades with different lifting angles (0°, 60°, 120° and 150°). Results were compared against the average measured stress and deformation. Overall, the simulations were able to capture the trends in the stress loading. The stress at points on the front and back of the blades were also monitored and also showed good convergence. Each simulation took approximately 2.2 hours to run on a Solid Works 2014 SP5 software.

3.0 Results and Discussion

3.1 Mesh Convergence Analysis for Designed Mulcher Blades

Significant variations were observed in the modulus distributions between the mesh densities of the four blades. Better results in different analysis with Solid Works software on mesh convergence study was explained on the four design tractor mounted mulcher blades.
3.2 Mesh Convergence Test Analysis for Blade with 0° Lifting Angle
The Table 2 presents result of convergence test analysis carried out on blade with 0o lifting angle. The test results revealed that by adding the number of elements, maximum stress increased sharply and then gradually remained stable. The analysis began with 8157 elements and rose until 302869 elements as it reached its finest stage as presented in the geometric and mesh models in Figure 3. In the initial test, maximum stress was 36.50 MPa, which increased up until 44.85 MPa in the final test at 302869 elements as shown in (mesh density distribution in the domain of the blade). Figure 4 shows the maximum stress at 181683 elements which discontinued its sharp increase at 42.43 MPa and maintained its very little escalation until the final point as graphically shown. Also from the calculations of stress change, the result showed that it was below 10%, therefore the result gave a good convergence.

Table 2: Convergence test analysis for blade with 0o lifting angle

Analysis	No. of Elements	Maximum Stress (MPa)	Maximum Displacement (mm)
1	8157	36.50	0.0174206
2	14126	37.78	0.0174505
3	23157	39.13	0.0174739
4	55778	40.46	0.0174841
5	181683	42.43	0.0175012
6	302869	44.85	0.0175085

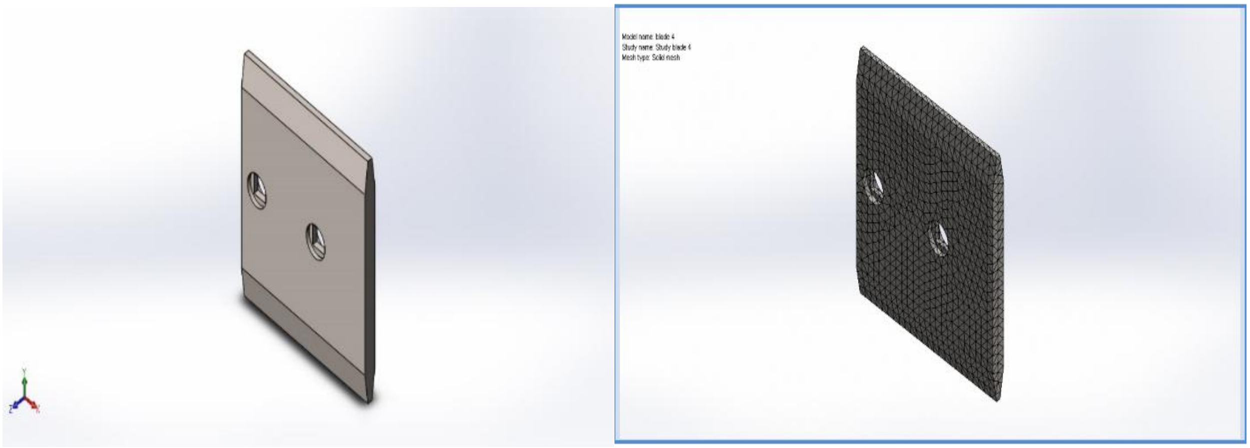

Figure 3: Geometric model and meshing density for blade with 0o lifting angle

Figure 4: Mesh density distribution in the domain for blade with 0° lifting angle

3.2.1 Maximum Stress and Deformation for Blade with 0° Lifting Angle

Table 3 presents the maximum stress and maximum deformation simulation results of the blade with 0° lifting angle. Maximum stress of 44.85 MPa was obtained at bottom of the blade which is indicated in red colour as shown in Figure 5. The stress at the tip of the blade had a low value of 1.000 MPa. The maximum deformation was found to be 0.0175 mm as shown in Figure 5. The stress results were compared with the yield point (62.04 MPa) of the blade material and established that the maximum stress did not exceed the yield point, which simply mean that deformation did not affect failure on the blade with 0° lifting angle.

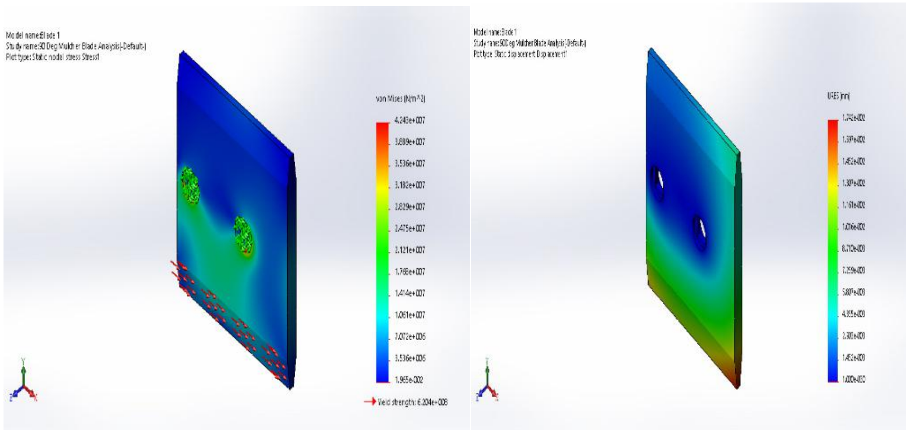

Figure 5: Maximum stress and maximum deformation for blade with 0° lifting angle

At the inner bolt holes, large amount of stress were traced which proposed that bolts that can endure stresses above 24.75 MPa can be used to tighten the blade to the mulcher's blade carrier in order to resist estimated stresses.

3.3 Mesh Convergence Test Analysis for Blade with 60° Lifting Angle

Table 4 shows results of convergence test analysis for blade with 60o lifting angle. Increasing the number of elements, maximum stress increased abruptly and then approximately remains steady. The mesh convergence analysis started with 4618 elements and increased until 177041 elements where it reached its finest stage as shown in Figure 6. The maximum stresses at 105763 elements, for the first and peak test, were 17.68 MPa and 20.41MPa, respectively. As shown at 177041 elements, maximum stress stopped its sharp increase at 19.99 MPa and kept slightly rising until the last point as shown in Figure 7. Also from the calculations of stress equation change, the result indicated that it was less than 10%, therefore the solution gave a good convergence.

Table 4: Convergence test analysis for blade with 60o lifting angle

Analysis	No. of Elements	Maximum Stress (MPa)	Maximum Displacement (mm)
1	4618	17.68	0.00572141
2	8312	18.04	0.00571822
3	14560	18.38	0.00572305
4	33171	18.64	0.00572872
5	105763	20.41	0.00573255
6	177041	19.99	0.00573563

Figure 6: Geometric model and meshing density for blade with 60° lifting angle

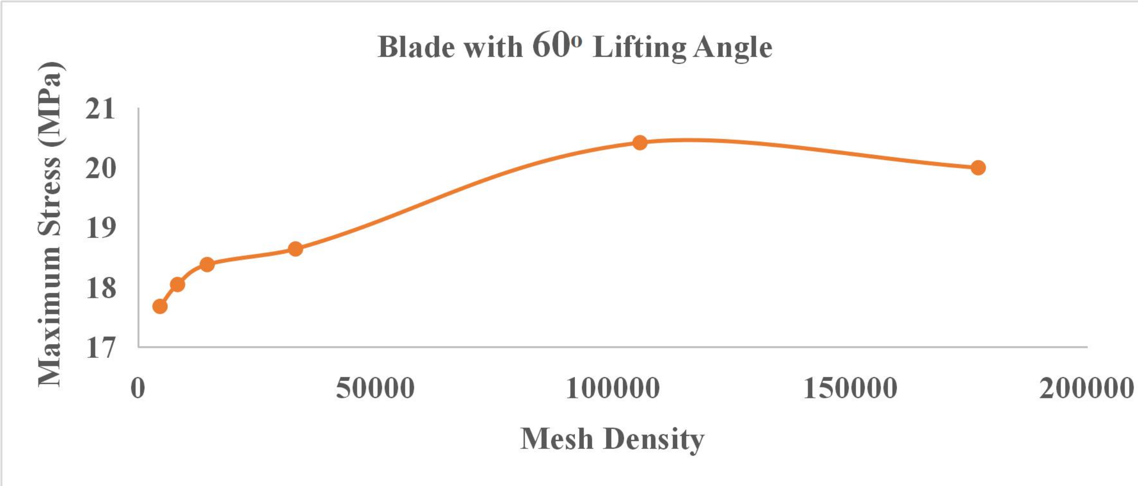

Figure 7: Mesh density distribution in the domain for blade with 60° lifting angle

3.3.1 Maximum Stress and Deformation for Blade with 60° Lifting Angle

Table 4 shows the simulation result for maximum stress and maximum deformation on the blade with 60° lifting angle. Maximum equivalent stress of 20.41 MPa at the top of the blade was obtained which is indicated in red colour in Figure 8 and a maximum total deformation of 0.0057 mm was obtained as presented. The stress results were equated with the yield point (62.04 MPa) of the blade material and found that the maximum stress did not exceed the yield point, which implied that deformation did not cause failure on the blade with 60° lifting angle.

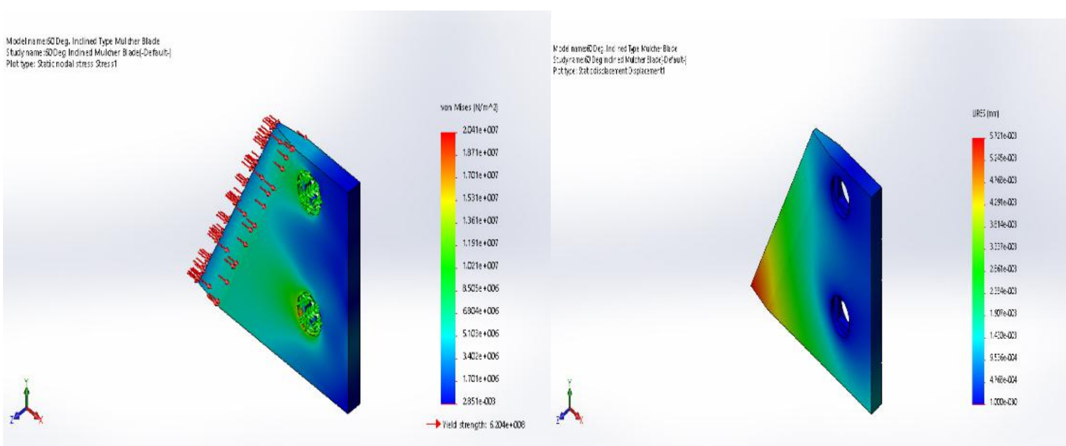

Figure 8: Maximum stress and deformation for blade with 60° lifting angle

Higher stress values were located at the inner bolt holes, which suggest that bolts that can withstand stresses above 11.91 MPa would be used to tighten the blade to the Mulcher's blade carrier in order to withstand anticipated stresses.

3.4 Mesh Convergence Test Analysis for Blade with 120° Lifting Angle

The analysis of convergence test was carried out on blade with 120° lifting angle and the results are presented in Table 5. The test result shows that by increasing the number of elements, maximum stress increased sharply and then suddenly remained constant. The analysis began with 4733 elements and increased until 197861 elements as it reached its optimum stage as shown in Figure 9. In the first test, maximum stress is 16.55 MPa, which increased up until 18.46 MPa in the finishing test at 112116 elements. As revealed at 197861 elements, maximum stress discontinued its sharp increase at 18.92 MPa and maintained its very little escalation until the final point as shown in Figure 10. Similarly, the calculations of stress change recorded that it was lower than 10%. Therefore the outcome gave a good convergence.

Table 5: Convergence test analysis for blade with 120° lifting angle

Analysis	No. of Elements	Maximum Stress (MPa)	Maximum Displacement (mm)
1	4733	16.55	0.0040438
2	9261	16.65	0.00404526
3	15613	17.34	0.00404775
4	35076	17.44	0.00404968
5	112116	18.46	0.00405174
6	197861	18.92	0.00405284

Figure 9: Geometric model and mesh density for blade with 120° lifting angle

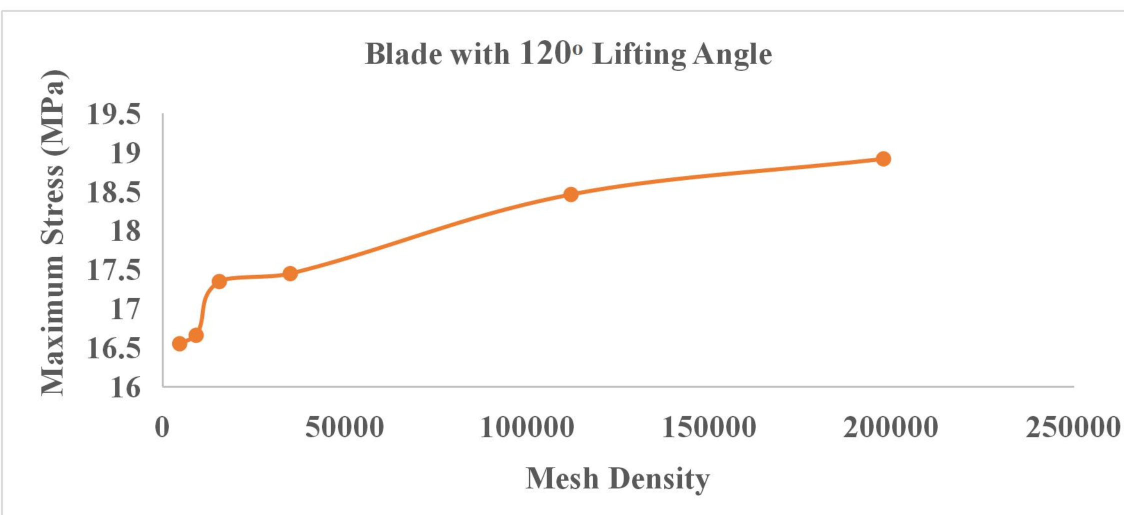

Figure 10: Mesh density distribution in the domain for blade with 120° lifting angle

3.4.1 Maximum Stress and Deformation for Blade with 120° Lifting Angle

Table 5 shows the Finite Element Analysis (FEA) of the geometric model, maximum stress and maximum deformation of the blade with 120° lifting angle. From the simulation effects, maximum stress on the blade with 120° lifting angle was 18.95 MPa as shown in Figure 11 which is indicated in red colour at the tip of the blade. The stress distributions were below the yield stress (62.04 MPa) of the stated blade material. Larger stress results were sited at the inner bolt holes, which suggest that bolts that can resist stresses above 6.26 MPa is recommended to tight the blade to the mulcher's blade carrier in order to sustain predicted stresses. The stress at the dorsal of the blade had a low value represented with a blue colour.

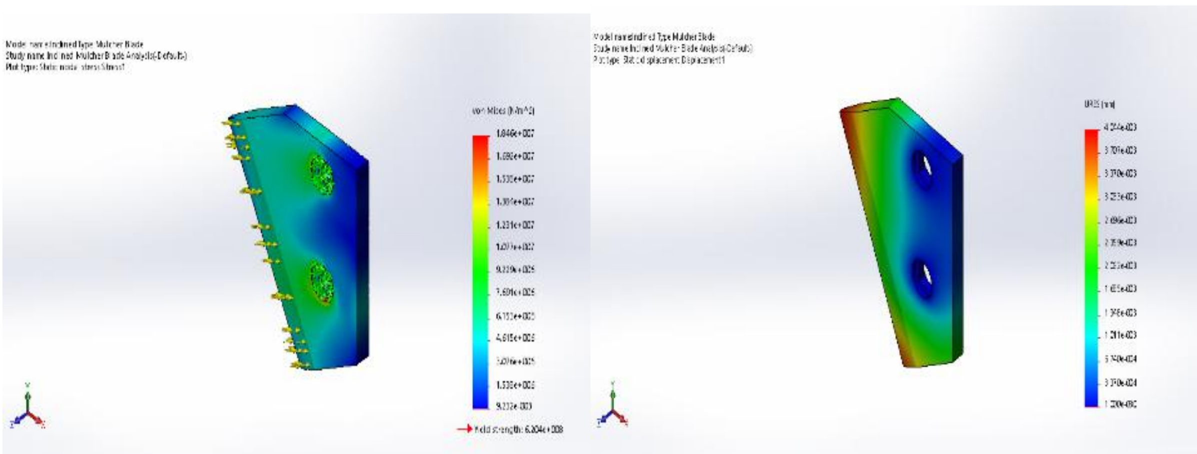

Figure11: Maximum stress and maximum deformation for blade with 120° lifting angle

The maximum deformation results for the blade with 120° lifting angle was 0.0041 mm as indicated in Figure 11. All deformation values were within the acceptable limit for the design intent and material specifications of the mulcher blade. The maximum deformation of the blade at the mid-section was due to the high amount of force the blade was required to be overcome during operation.

3.5 Mesh Convergence Test Analysis for Blade with 150° Lifting Angle

Convergence test was performed on the blade with 150° lifting angle and the analysis are presented in Table 6. The test effects show that by increasing the number of elements, maximum stress increased sharply and then abruptly remained stable. The analysis started with 7034 elements and increased until 292180 elements as it reached its optimum stage as shown in Figure 12 the geometry and mesh models. In the first test, maximum stress was 66.87 MPa, which increased up until 73.35 MPa in the finishing test at 175532 elements. The maximum stress at 292180 elements discontinued its sharp increase at 73.35 MPa and maintained its very little escalation until the final point as shown in Figure 13. Similarly, the calculations of stress change on convergence test shows that it was lower than 10%, therefore the outcome gave a good convergence.

Table 6: Convergence test analysis for blade with 150o lifting angle

Analysis	No. of Elements	Maximum Stress (MPa)	Maximum Displacement (mm)
1	7034	66.87	0.0174249
2	13990	67.80	0.0174424
3	23030	69.38	0.0174807
4	53166	71.60	0.0175034
5	175532	73.35	0.0175301
6	292180	74.29	0.0175376

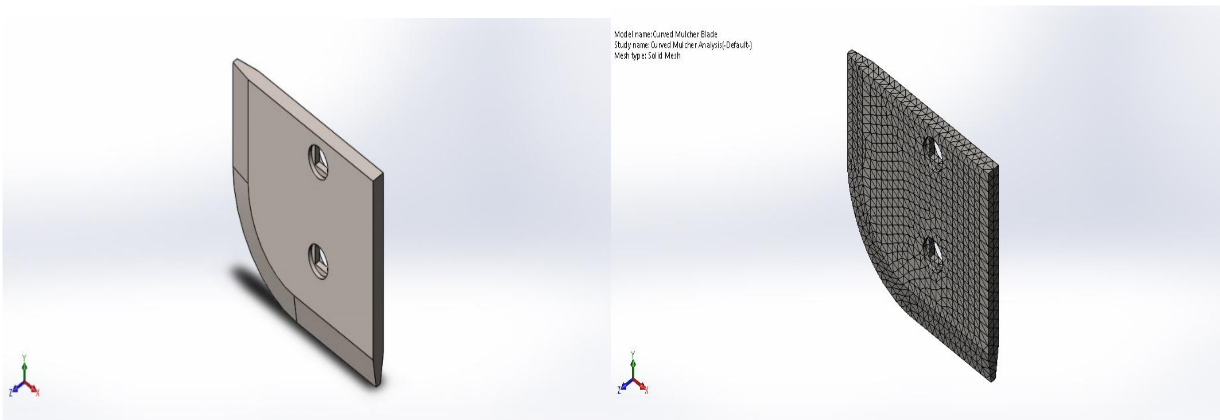

Figure 12: Geometric model and meshing density for blade with 150o lifting angle

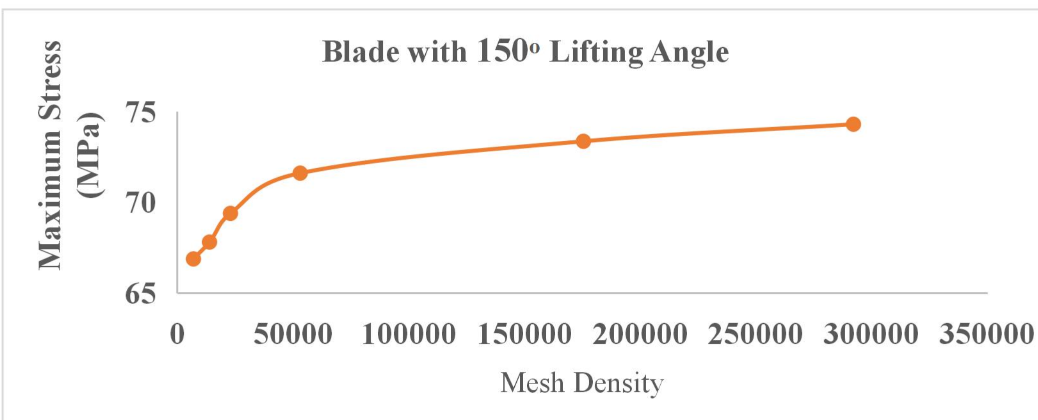

Figure 13: Mesh density distribution in the domain for blade with 150o lifting angle

3.5.1 Maximum Stress and Deformation for Blade with 150° Lifting Angle

Table 6 presents the FEA of the geometric model, maximum stress and maximum deformation of the blade with 150° lifting angle. From the simulation effects, maximum stress on the blade with 150° lifting angle was 74.29 MPa as shown in Figure 14 which is indicated with red colour at the tip of the blade. The stress distributions were above the yield stress (62.04 MPa) of the specified blade material, the blade was the worst in terms of failure due to fatigue. Larger stress results were sited at the inner bolt holes, which suggest that bolts that can resist stresses above 32.26 MPa are recommended to tight the blade to the mulcher's blade carrier in order to sustain predicted stresses. The stress at the top of the blade represented with a blue colour had a low value. Maximum deformation result for the blade with 150° lifting angle was 0.0175 mm as indicated in Figure 14.

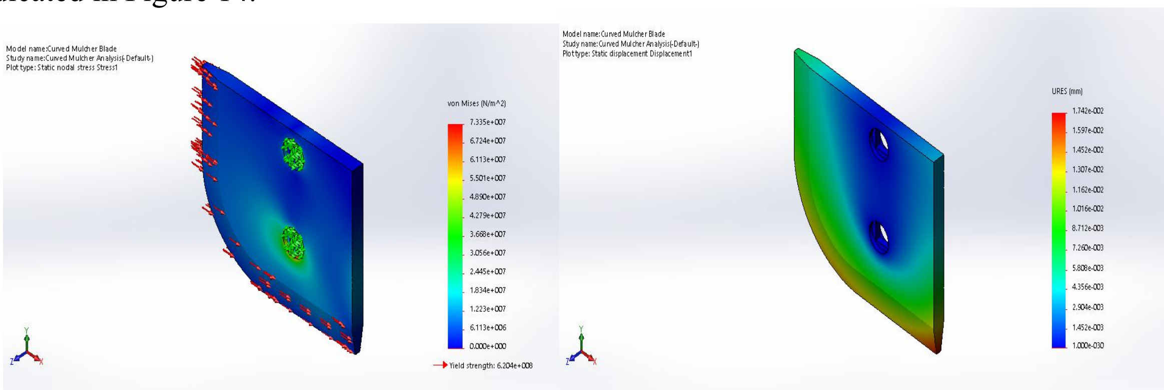

Figure 14: Maximum stress and maximum deformation for blade with 150° lifting angle

The blade geometry, material properties, bolt placements and blade thickness played a significant roles which accounted for the stress and deformation differences in the blade concepts. (Bosrotsi et al.), (2017) reported that blades with higher stress and deformation values have shorter design life (high rate of wear and fatigue). From Tables 1- 6, the results indicate that the blade with 120° lifting angle gave minimal stress and deformation values than the other blades with 0°, 60° and 150° lifting angles. Hence, the blade with 120° lifting angle was recommended over the other blades.

4.0 Conclusion

Based on the research conducted on simulating the blades of tractor mounted mulcher for mulching oil palm fronds prior to replanting period, the following conclusions can be drawn. Minimum stress and deformation requirement for finite element analysis were achieved by blade with 120° lifting angle. The worst performing blade was the one with 150° lifting angle.

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