Development of Cutter Head Design in Cutter Suction Dredger with Thickness and Pitch Variation

Amiadji[1], Achmad Baidowi[2], Riyan Prayogo[3]

Abstract— the need for dredgers for the shallow water in the sea with a very high level of siltation on the coast of Indonesia is a factor worth considering. For example, coastal areas in Ujung Pangkah sub-district, Gresik district, East Java province. The choice of the area is due to the many institutions and corporations that are back and forth utilizing these waterways. But the main obstacle to making a Cutter Suction Dredger (CSD) is almost all the equipment needed is imported, for example, the main equipment is the cutter head. Therefore looking at the needs, economics and technology factors, this paper will discuss the cutter head design. Available data is a request from the owner, 40KW power cutter head; 1000mm cutter diameter; 30rpm rotation. The force distribution given 5950 N is in accordance with the dredging condition which is to have a strong material tension to be estimated to work at a relatively Soft density of <100 Mpa and Medium around 100Mpa - 170Mpa. The expected results of this design are to obtain a proportional design before the production process and to function at a minimum according to specifications. The usefulness of this design really hopes to be followed up to the production stage and can be applied.

Keywords—CATIA, Cutter Suction Dredger (CSD), Cutter Head.

I. INTRODUCTION

Ujung Pangkah is one of the coastal areas in Gresik Regency, East Java which has experienced a lot of sedimentation due to sediment carried by the Bengawan Solo river. The results showed that the coastline in Ujung Pangkah experienced many changes due to accretion and abrasion. The accretion area reached 11.35 km² and abrasion was 5.19 km in a period of 15 years [1]. One example of a sedimentation contributor is the Bengawan Solo river where the estuary of the longest river in Java carries material with deposits reaching 2.79 kg / m³ [2].
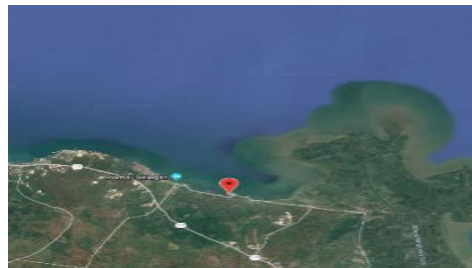

Figure 1. Maps sub-distric. ujung pangkah.

The dredging flow is determined by the condition of the land which can be in the form of mud, sand, sandy mud or rock, generally coastal lands in Indonesia in the form of mud or sandy mud [3]. From the study above, the biggest obstacle is in shallow sea conditions.
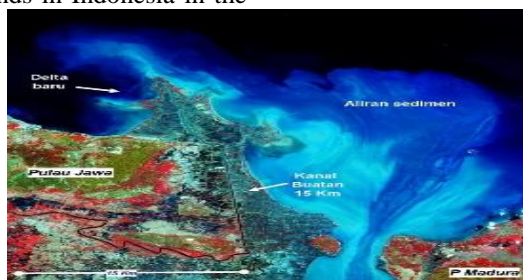

Figure 2. Sediment flow

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A dredger is a piece of equipment that can dig, carry, disposed with a certain amount of soil below water level at a certain time. For example, water is flowed using a dredge pump through a suction pipe. The type of dredger to be used is the cutter suction dredger. To solve the

problem, we must complete the design one by one and make sure that it can work accordingly by carrying out

design simulations. We provide screenshots to visualize and make it easy to understand below.
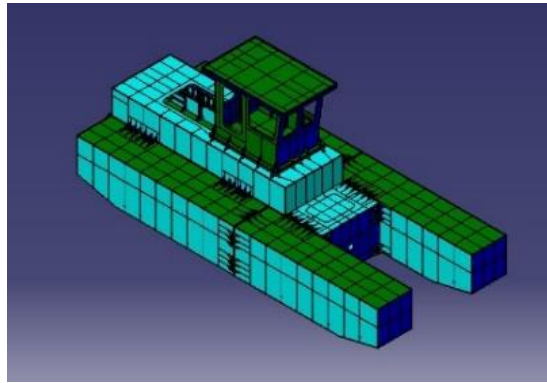

Figure 3. 3D construction from cutter suction dredger.

II. METHOD

A. Cutter Suction Dredger

Cutter Suction Dredger (CSD) is a digging tool of soils that are moved using a rotating cutter head that is driven hydraulically or mechanically. The mud pump inside the ship is primarily used to suck material and move to the surface and remove both into the barge or other according to plan. There are 2 main types for CSD, which do not have a propeller made similar to a barge or pontoon or have their own propeller (self-propelled) [4]. There are two types of cutter head motion, that are overcutting and undercutting [5]. The ability of the cutter teeth is planned to operate within 8m depth with the prediction of the soil density at a relatively soft of <100 Mpa and Medium around 100 Mpa - 170 Mpa. To ensure the toughness of cutter teeth, wear out durability should be higher than abrasive durability, which the value is 3 to 4 times that of conventional steel equipment [6]. There are several types of dredgers that can be seen in Figure 4.

B. Type of Soil

The types of soil and rock material found near the coast refer to the geology of Keeper Reef by showing the condition of a cross-section along 720m with depths up to 22m [7].
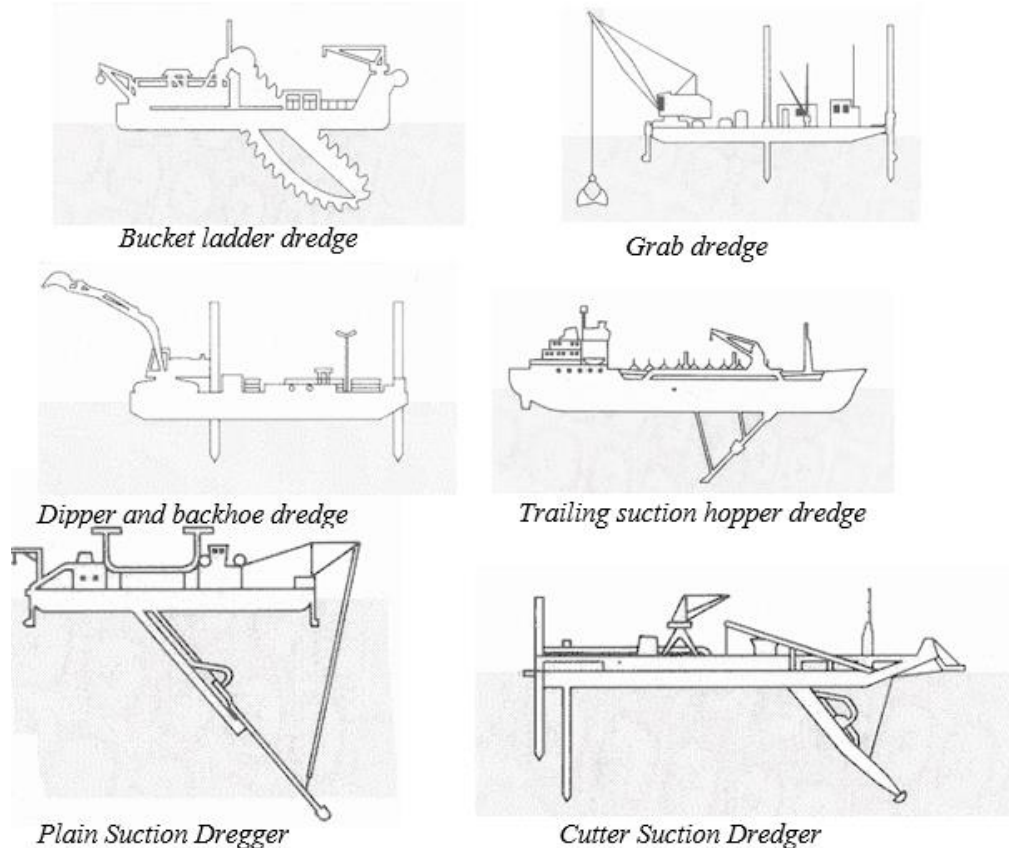

Bucket ladder dredge

Grab dredge

Dipper and backhoe dredge

Trailing suction hopper dredge

Plain Suction Dregger

Cutter Suction Dredger

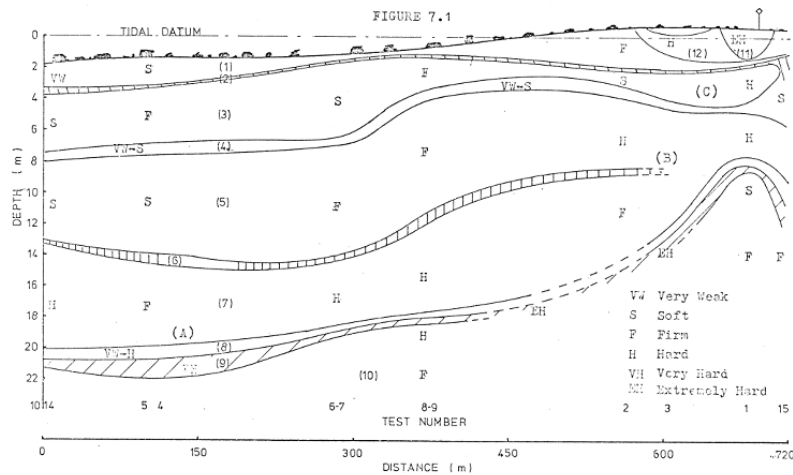**Figure 4.** Kind of Cutter Suction Dredger

Figure 5. The composition of the soil material to a depth of 20m [7].

Specific classification above can be used as a basis for consideration of material that used for dredging. The CSD designed in this study has a depth of up to 8m. By referring to the cross-section of the formation of soil material layers, it can be predicted that the material to be dredging is to have a relative density (S) Soft and (F) Firm. For the types of material that might appear in the area can be seen in the table.

TABLE 1.
GENERAL INDICATION OF CUTTER TYPE SELECTION [8]

Relative Density	Material Strength	Possible Material	Cutter Selection
Soft	0-100 Mpa	(S) – Salt (S) – Coarse-grained, weakly cemented sandstones (S) – Fossiliferous limestones (I) – Altered igneous rocks (S) – Claystones, shales (S) - Coal	Partial Face Pick
Medium	100-170 Mpa	(S) – Marlstones, Limestones (M) – Marble (S) – Shales, siltstones, sandstones (M) – Phyllites (M) – Highly micaceous schists (M) – Altered intrusive igneous rocks (M) – Altered metamorphic rocks	Heavy Partial Face Pick Marginal Full Face Disc
Hard	170-240 Mpa	(M) – Slates (S) – Crystalline limestone (I) – Diabase (S) – Silicious, cemented sandstones (M) – Gneisses and schists (I) – Pyroxenites (I) – Coarse-grained granites	Full face discs Marginal Full face carbide button cutters
Very Hard	240 Mpa	(M) – Quartzites (M) – Amphibolites (S) – Dolomites (I) – Fine-grained granites (I) – Basalt, diabase (I) – Syenites (I) – Gabbros	Blasting

Rock classes:
(S) Sedimentary
(I) Igneous Rocks
(M) Metamorphic

Note: current on-going research suggests both thresholds of pick and discs could be increased significantly with the use of high-pressure water jet assisted cutting.

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The ability of the Cutter's teeth is planned to operate within 8m with the prediction of working soil material at a relatively Soft density of <100 Mpa and for Medium around 100 Mpa - 170 Mpa. To ensure the toughness of cutter teeth, wear resistance must be higher than abrasive resistance where the value is 3 to 4 times that of conventional steel equipment [6]. The hardness of the cutter material standard must be 40 HRC (Rockwell C Hardness) or 373 HB (Brinell Hardness) or 388 HV (Vickers Hardness) or minimum cutter material voltage of 1265 N/mm² [9]. The type of cutter teeth material to be used is the S2 series Stell Alloy which has a hardness value of 440-520 HB and a yield of 1500 N/mm². The S series type is intended for shock resisting [10], other suitable alloy materials can be seen in ASTM-A681.

C.   Stress Analysis

Stress Analysis is a science of engineering that uses methods to determine the stresses and strains of materials and structures that are subjected to force. In mechanics, the definition of stress is a physical quality that shows the strength of internal particle bonds.

To speed up the analysis process and maintain the accuracy of 3D results and stress analysis multi-platform commercial CAD / CAM / CAE developed by the French company "Dassault Systemes" and marketed worldwide by IBM, and written in C ++ programming language, and CATIA is the foundation of the Dassault Systemes Product Lifecycle Management software suite. This software is not only used to conFigure 2D and 3D because this multi-platform CAD / CAM / CAE software can also be used for planning and designing the machining process of a product, making simulations, and analyzing the characteristics of the product. The difference in manual calculations and computational calculations by use CATIA software should be less than 7% [11].
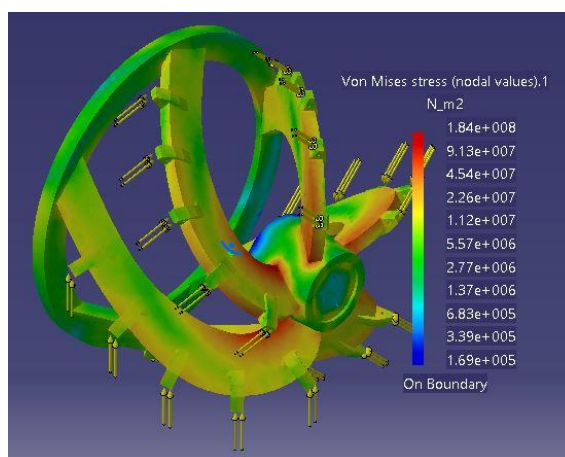

Figure 6. CATIA stress analysis.

D.   The effect of Stress Analysis on Head Cutter

Many parameters influence, from the most basic things, namely the type or classification of soil material that will be processed dredging and knowing the strength of the material strain into consideration before entering the design process.

For the second parameter, the ability of the dredging tool itself. If it is described in a complex manner, there are certainly many factors that affect it, but as a limitation, dimension parameters of the cutter blade to be used in this analysis. The material that has been used in this analysis is the type of mild steel grade A material for marine use, and for the dimension parameter, the parameters for the change in angle and thickness that has been varied to be more clear in Figure 6.

To facilitate classification based parameter above then our working condition (WC) present in Table 2. Each WC has been subjected to a stress analysis with the following output targets:
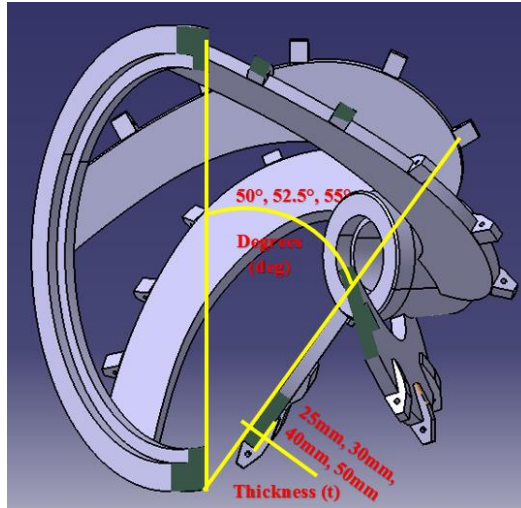
Figure 7. Parameters change in angle and thickness.

TABLE 2.
CLASSIFICATION WORKING CONDITION (WC).

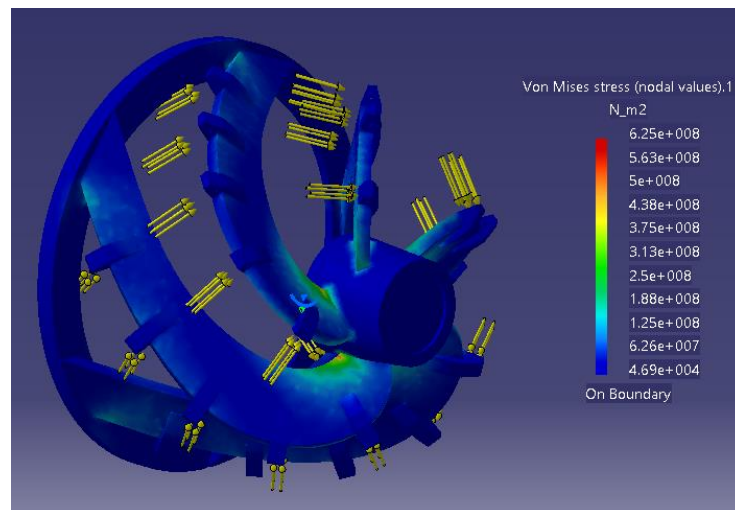| Degree Thickness	50°	52.5°	55°
25mm	WC1A	WC1B	WC1C
35mm	WC2A	WC2B	WC3C
40mm	WC3A	WC3B	WC3C
50mm	WC4A	WC4B	WC4C

Figure 8. An example of the results of Von Mises Stress is stress analysis.

E.   Determination of Dimensions and Parameters

Data available at the request of the owner has the following specifications: 40KW power cutter head; 1000mm cutter diameter; 30rpm rotation. The schematic diagram of the cutter head design is as follows:
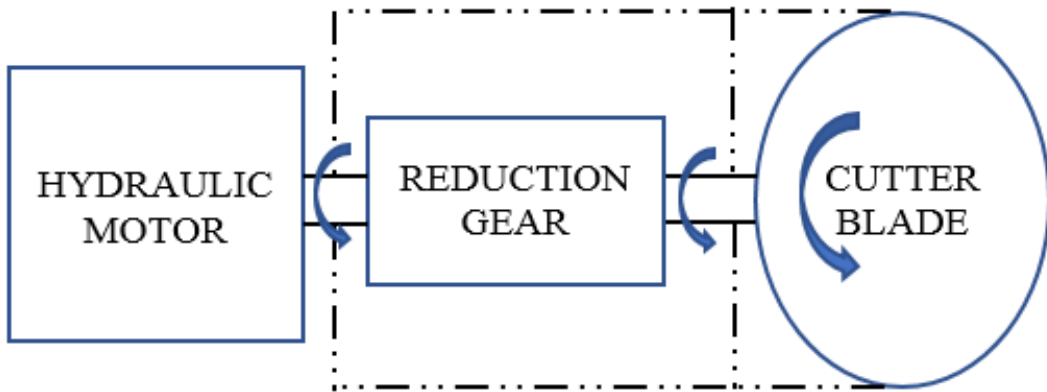
Figure 9. Cutter head planning diagram scheme.

F.   Basic theory

When the material is given it will produce bending stress. Bending stress is a type of normal stress but a little more specific.

In general, to get bending stress can use the formula below:

$$\sigma_b = \frac{M_b}{Sx} \tag{1}$$

Where:
σb = Bending Stress (N/mm²)
Mb   = Bending moment (N·mm)
Sx   = Plastic Section Modulus (mm³)

Basically, to match the radial force given to the blade cutter then the force direction is like Figure 9.
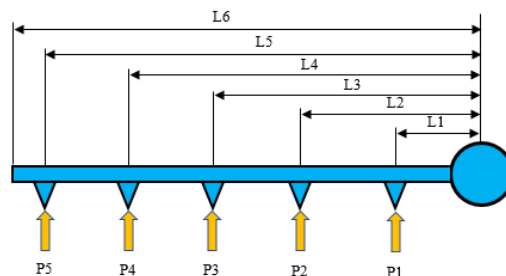
Figure 10. Radial cutter blade style

Where :
P   = Force (N)
L   = Length from the center (mm)
ΣMb   = Total of moment (N·mm)

So :
$$\Sigma Mb = (L1 \cdot P1) + (L2 \cdot P2) + (L3 \cdot P3) + (L4 \cdot P4) + (L5 \cdot P5) \tag{2}$$

Because the force required at each point is not known, the force required for the soil dredging process can use the following equation [12]:

$$R_1 = k_1 \cdot b \cdot S_t \tag{3}$$

where:
R_1 = Resistance (N)
k_1 = Specific resistance cutting of soil (N/m²)
b   = Width of the blade (m)
St   = Thickness cutting layer (m)

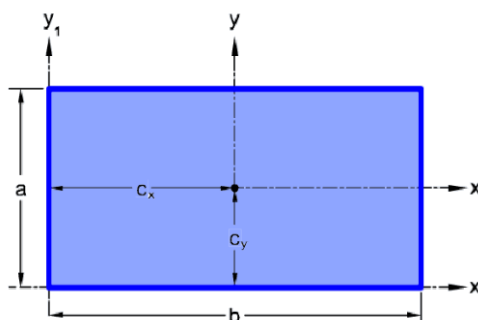The cross-section of the cutter blade is rectangular, so the geometry can be seen in Figure 10.

Figure 11. Section profile of cutter blade.

So that in general the plastic section modulus can be determined as follows:

$$Sx = \frac{a^2 \cdot b}{4} \qquad \textbf{(4)}$$

Where :
Sx = Plastic section modulus (mm³)

Power determination uses the following equation:

$$P = T \cdot \omega \qquad \textbf{(4)}$$

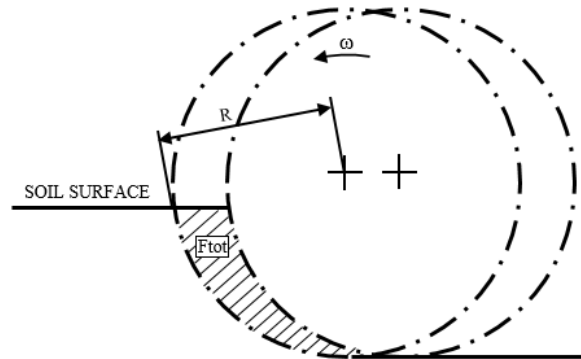Where :
P = Power (kW)
T = Torque (Nm)
ω = Angulat speed (rad/s)

Figure 12. Distribution in circle segments.

From the Figure above, then:
For equations look for torque in general as follows [13]:

$$T = R \cdot F_{tot} \qquad \textbf{(5)}$$

While for the equation looking for angular speed in general as follows:

$$\omega = \frac{(2 \cdot \pi \cdot n)}{60} \qquad \textbf{(6)}$$

So, the equation looks for the rotational power of the rotor to be:

$$\textbf{P} = \textbf{R} \cdot \textbf{F}_{\textbf{tot}} \cdot \frac{\textbf{(2} \cdot \boldsymbol{\pi} \cdot \textbf{n)}}{\textbf{60}} \qquad \textbf{(7)}$$

III. RESULT AND DISCUSSION

A. Modeling of the cutter Head and Blade Cutter

Cutter head and blade cutter will be used in this research as the main object. It will be observed and analyze which one from this object will generate great results.

A. 3D Modeling and 2D Drawing

The main part of the cutter blade itself is there is a knife for the dredging gear, the hub for the shaft house, and the ring for reinforcement on the outside. Design parameters of the blade for the cutting gear spot; design of a hub shape; the material used; and the main parameters raised in this study are according to the results of previous calculations and planning. For the results of geometry modeling using CAD software and for 3D modeling using CATIA V5 software can be seen in the Figure below.
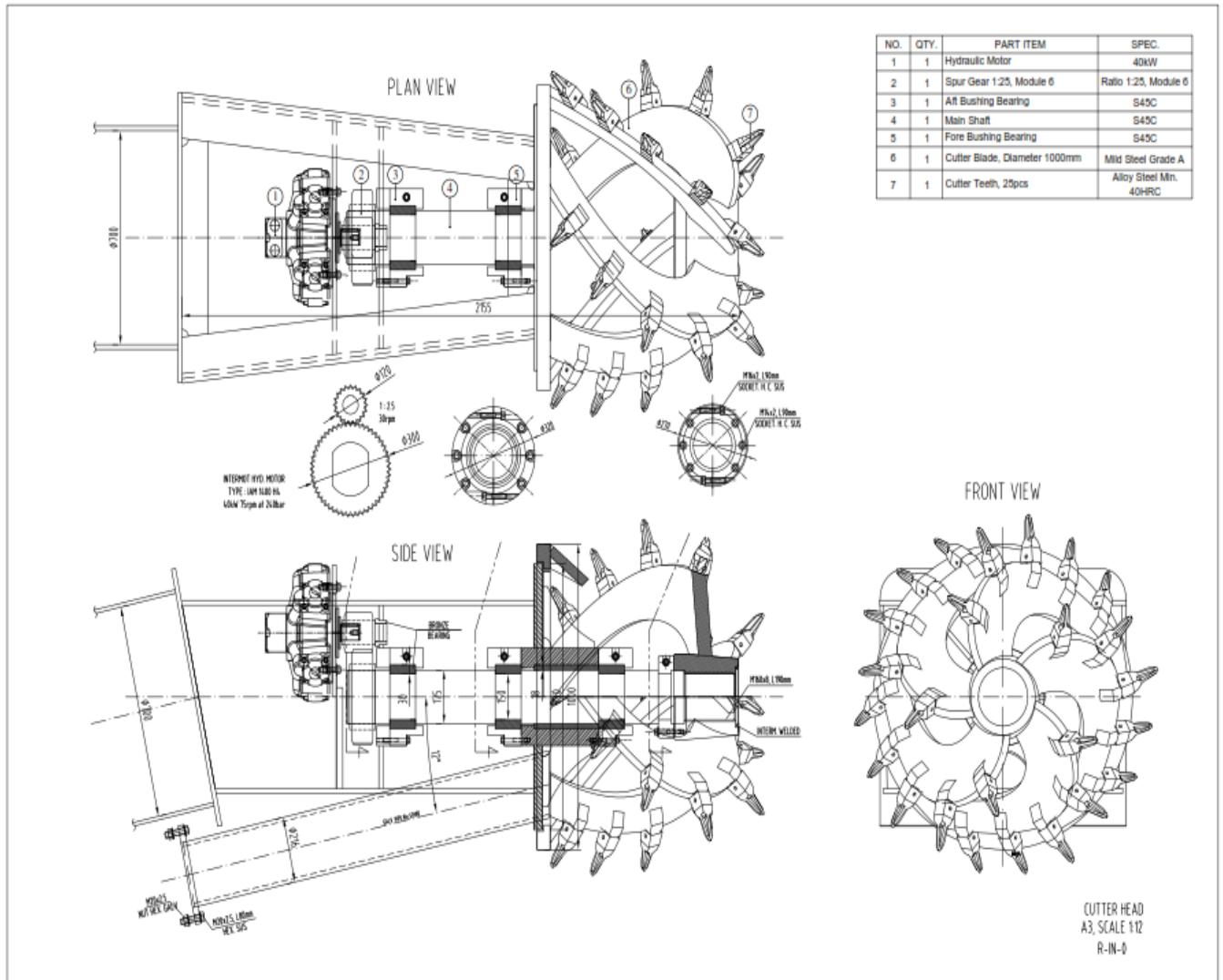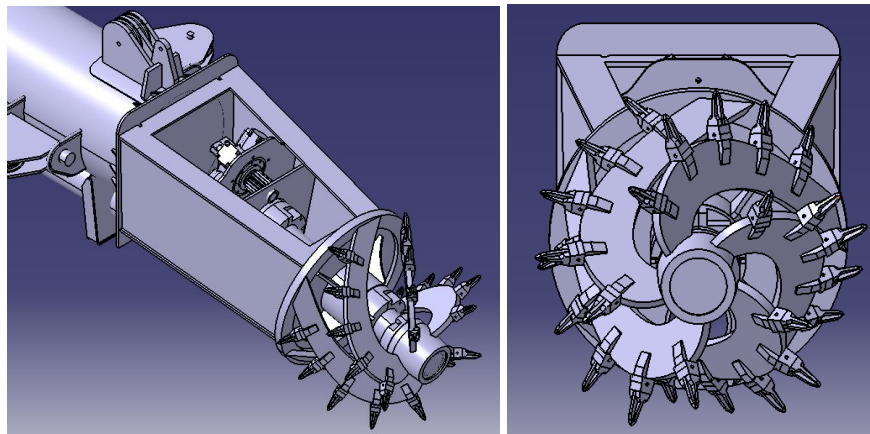
Figure 13. 2D drawing of Head Cutter.

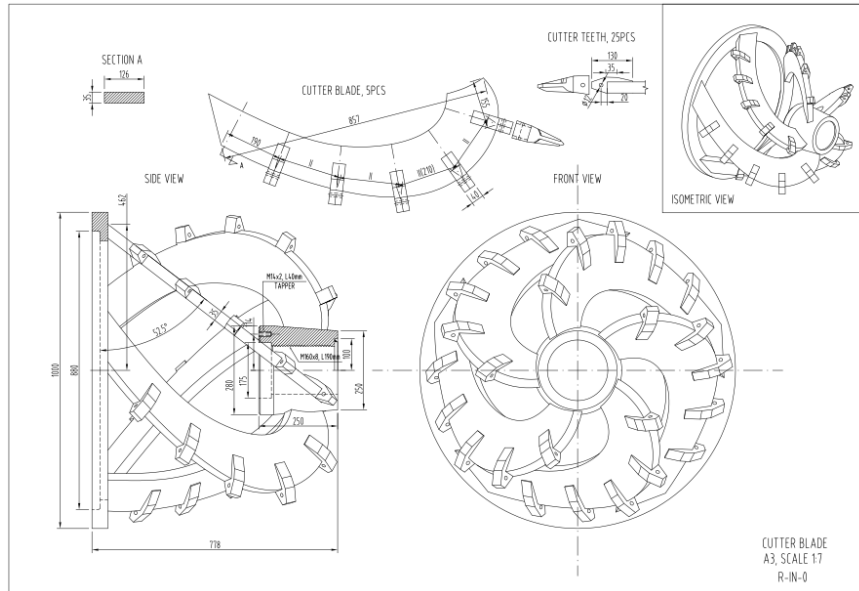**Figure 14.** 3D Model drawing of Cutter Head.

Figure 15. 2D of Cutter Blade.

Figure 16. 3D Model drawing of Cutter Blade.

B.   Convergence of Mesh Refinement

Finite Element Method (FEM) can be described as a numerical simulation method that is used to estimate the response/behavior of a component/system under certain conditions, by dividing the component/system in question into smaller (discretized) parts called element, with a certain number (finite). In the literature on finite element methods (FEM), it is often mentioned that the accuracy of the finite element solution increases with the increasing number of elements used, but with the increasing number of elements used, the time needed for computing is also greater. Even sometimes the number of elements that are too large will increase the round-off error.

In the application, one of the recommendations for determining the number of elements with the accuracy of an acceptable solution in a finite element analysis is to conduct a convergence test (convergence test) on the solution obtained. The example is the stress analysis on a component, the initial analysis is carried out with the size/number of certain elements, the solution is obtained by completing the model used. The analysis is then repeated with a larger number of elements, the value of the stress at a particular location compared to the results of the previous analysis. If the difference in voltage values between the two analyzes is quite large, then the analysis is repeated again with a larger number of elements until the difference is considered quite small.
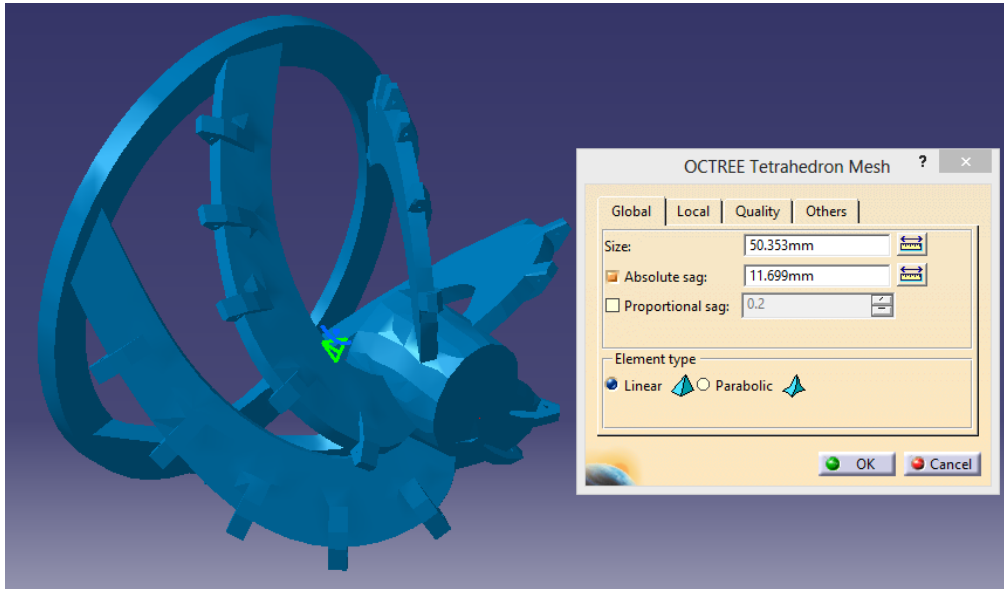
Figure 17. Setting meshing size.

In material science and engineering, the von Mises yield criteria can also be formulated in von Mises stress or equivalent tensile stress, σv, the scalar stress value can be calculated from the voltage sensor [14]. In this case, the results of convergence can be seen in the table below:

TABLE 3.
TABLE OF CONVERGENCE OF CATIA V5 GENERATE STRUCTURAL ANALYSIS SOFTWARE.

| Type	Tetrahedron				
Size	30mm	24mm	20mm	18mm	15mm
Nodes	6963	11020	15981	19997	30831
Element	22359	37770	57750	74276	120354
Index	Value (N/m²)	Value (N/m²)	Value (N/m²)	Value (N/m²)	Value (N/m²)
10	1.43E+08	1.65E+08	1.94E+08	1.95E+08	1.95E+08
9	7.98E+07	8.96E+07	9.81E+07	1.01E+08	9.56E+07
8	4.46E+07	4.87E+07	4.98E+07	5.26E+07	4.68E+07
7	2.50E+07	2.65E+07	2.52E+07	2.73E+07	2.29E+07
6	1.40E+07	1.44E+07	1.28E+07	1.42E+07	1.12E+07
5	7.80E+06	7.82E+06	6.49E+06	7.37E+06	5.50E+06
4	4.36E+06	4.25E+06	3.29E+06	3.83E+06	5.50E+06
3	2.44E+06	2.31E+06	1.67E+06	1.99E+06	1.32E+06
2	1.36E+06	1.26E+06	8.45E+05	1.03E+06	6.45E+05
1	7.62E+05	6.83E+05	4.29E+05	5.37E+05	3.16E+05
0	4.26E+05	3.71E+05	2.17E+05	2.79E+05	1.55E+05
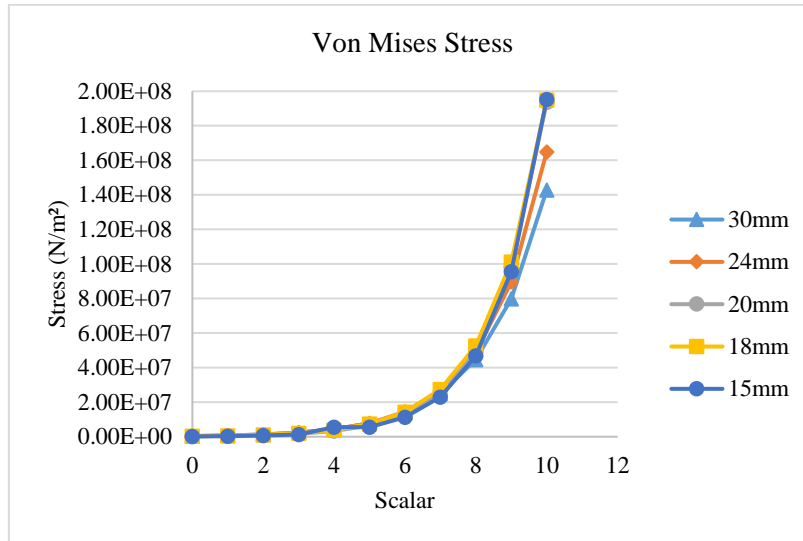
Figure 18. The results of the computational variation of meshing between Von Mises Stress and Scalar.
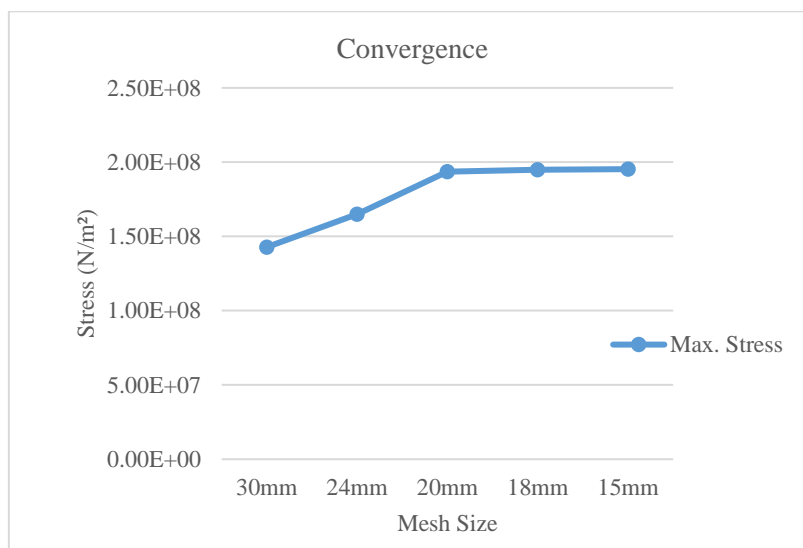

Figure 19. Convergence results in max. stress condition.

Computing above is given a force on each mounting of cutter teeth with a total of 25 points of distribution force with a value of 5950N according to the maximum calculation of load design. So that the convergence of the results of computational analysis can be obtained that the type of meshing that has been used for the analysis process has been Tetrahedron with a minimum size of 18mm; nodes 19997; and element 74276 because in these conditions the computational process has stabilized or convergence with a maximum yield of 1.95E+08 N/m².

C. Influences of Thickness Variations and Pitch Angles

1) Analysis of Working Condition A (WCA)

In WCA conditions constant pitch angle at an angle of 50° with a force of 5950 N/mm² is varied by 4 Working Condition with changes in thickness of blade material per condition, namely: WC1A = 25mm; WC2A = 35mm; WC3A = 40mm; WC4A = 50mm. Continued using a numerical method by using a type of Tetrahedron Mesh with a size of 17mm obtained by each computational result as shown in table 4.
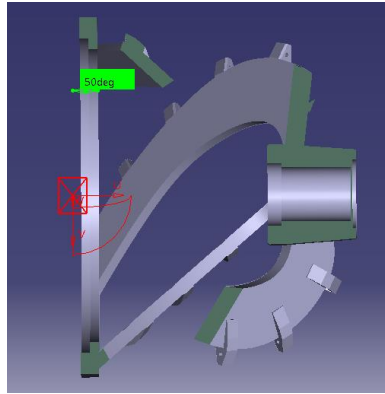
Figure 20. Section pitch conditions at 50°.

TABLE 4.
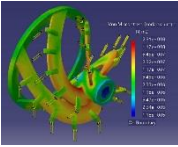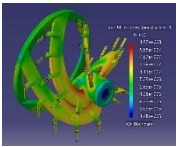DISTRIBUTION VALUE OF VON MISES STRESS AT THE PITCH ANGLE.

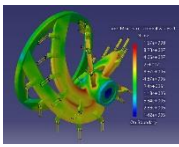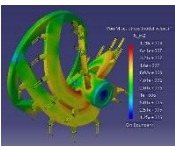| Degree	50°			

Condition	WC1A	WC2A	WC3A	WC4A
Thickness	**25mm**	**35mm**	**40mm**	**50mm**
Nodes	**21495**	**23057**	**23633**	**24932**
Element	**78293**	**86972**	**90662**	**98136**
Index	**Value (N/m²)**	**Value (N/m²)**	**Value (N/m²)**	**Value (N/m²)**
10	2.51E+08	1.97E+08	1.67E+08	1.28E+08
9	1.17E+08	9.59E+07	8.23E+07	6.41E+07
8	5.43E+07	4.67E+07	4.06E+07	3.21E+07
7	2.52E+07	2.28E+07	2.00E+07	1.60E+07
6	1.17E+07	1.11E+07	9.87E+06	8.02E+06
5	5.45E+06	5.40E+06	4.87E+06	4.01E+06
4	2.53E+06	2.63E+06	2.40E+06	2.01E+06
3	1.18E+06	1.28E+06	1.18E+06	1.00E+06
2	5.47E+05	6.23E+05	5.84E+05	5.01E+05
1	2.54E+05	3.03E+05	2.88E+05	2.51E+05
0	1.18E+05	1.48E+05	1.42E+05	1.25E+05

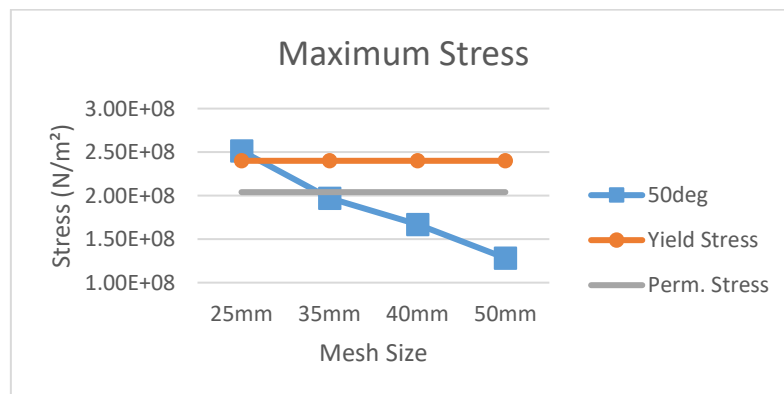**Figure 21**. Von Mises Stress results at a 50 ° pitch angle.

Figure 22. Maximum Von Mises Stress at 50 ° pitch angle.

From the results of computations with a pitch 50° angle, we can get that the material included in the allowable stress category is 35mm thick with a maximum voltage of 1.97E+08 N/m², 40mm thick with a maximum voltage of 1.67E+08 N/m², and thick 50mm with a maximum of 1.28E+08 N / m².

2)   Analysis of Working Condition B (WCB)

In WCB conditions a constant pitch angle at an angle of 52.5° with a force of 5950 N/mm² is varied by 4 Working Condition with changes in thickness of blade material per condition, namely WC1B = 25mm; WC2B = 35mm; WC3B = 40mm; WC4B = 50mm.
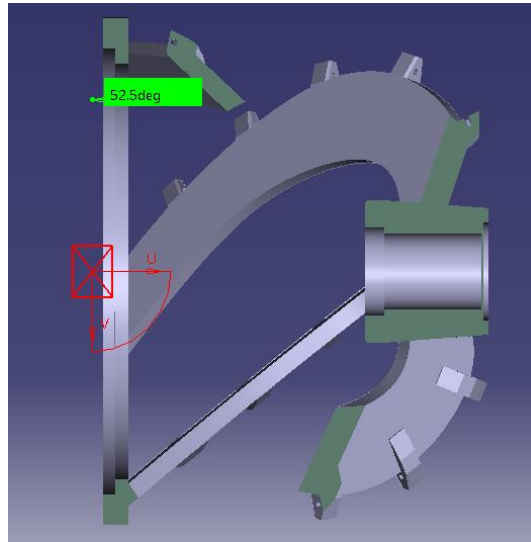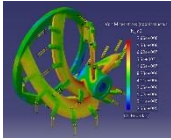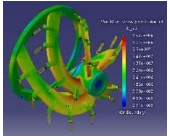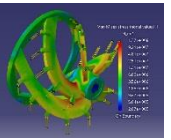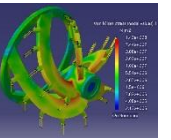

Figure 23. Section pitch conditions at 52.5°.

TABLE 5.
DISTRIBUTION VALUE OF VON MISES STRESS AT THE PITCH ANGLE 52.5°.

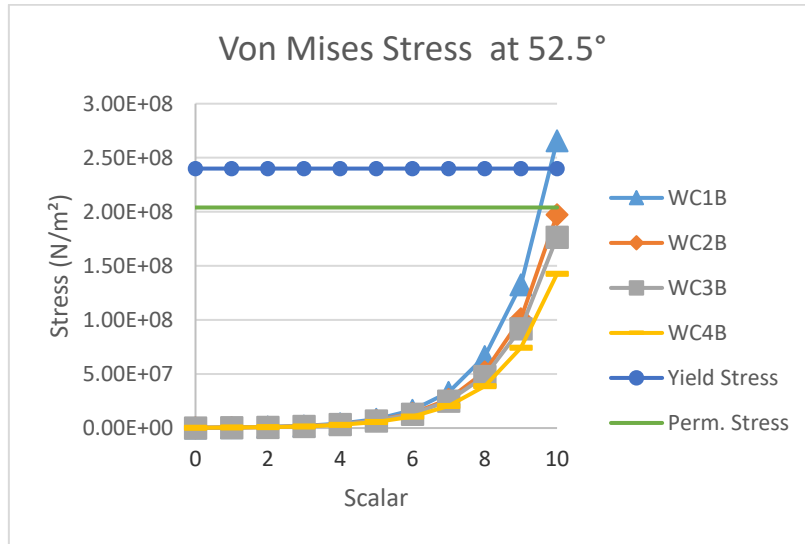| Degree	52.5°			
Condition	**WC1B**	**WC2B**	**WC3B**	**WC4B**
Thickness	**25mm**	**35mm**	**40mm**	**50mm**
Nodes	**21905**	**23642**	**23227**	**24780**
Element	**80229**	**89084**	**89120**	**97272**
Index	**Value (N/m²)**	**Value (N/m²)**	**Value (N/m²)**	**Value (N/m²)**
10	2.66E+08	1.97E+08	1.77E+08	1.43E+08
9	1.33E+08	1.01E+08	9.21E+07	7.44E+07
8	6.62E+07	5.20E+07	4.81E+07	3.88E+07
7	3.30E+07	2.67E+07	2.51E+07	2.02E+07
6	1.65E+07	1.37E+07	1.31E+07	1.06E+07
5	8.23E+06	7.04E+06	6.82E+06	5.51E+06
4	4.11E+06	3.61E+06	3.56E+06	2.87E+06
3	2.05E+06	1.86E+06	1.85E+06	1.50E+06
2	1.02E+06	9.53E+05	9.67E+05	7.82E+05
1	5.11E+05	4.89E+05	5.04E+05	4.08E+05
0	2.55E+05	2.51E+05	2.63E+05	2.13E+05

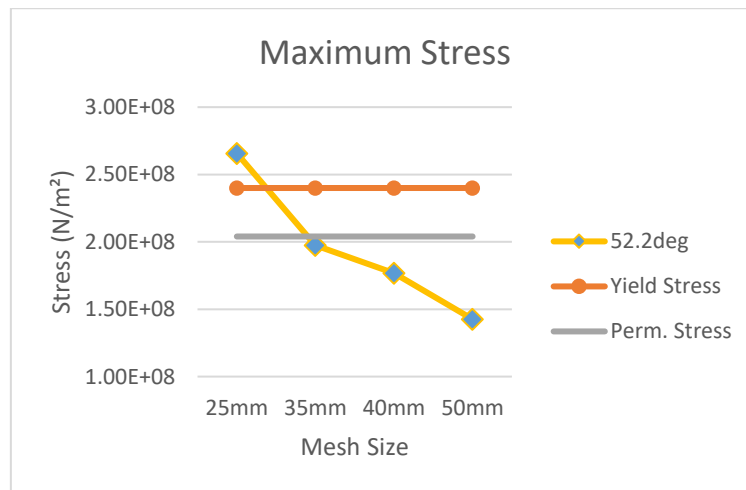**Figure 24.** Von Mises Stress results at 52.5° pitch angle.

Figure 25. Maximum Von Mises Stress at 52.5° pitch angle.

From the computation results with a pitch of 52.5° we can find that the material included in the permissible stress category is 35mm thick with maximum stress 1.97E+08 N/m², 40mm thick with maximum stress 1.77E+08 N/m² and thick 50mm with a maximum of 1.43E+08 N/m².

3) Analysis of Working Condition C (WCC)

In WCC conditions the condition of a constant pitch angle at an angle of 55° with a force of 5950 N/mm² is varied by 4 Working Condition with changes in thickness of blade material per condition, namely: WC1C = 25mm; WC2C = 35mm; WC3C = 40mm; WC4C = 50mm.
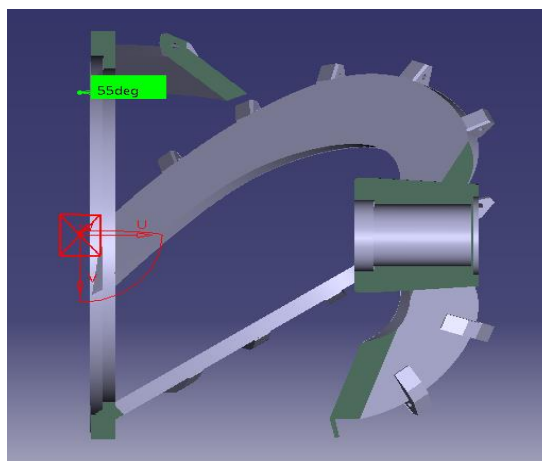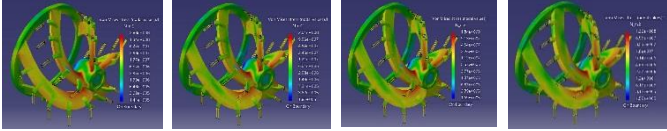

Figure 26. Section pitch conditions at 55°.

Continued using a numerical method by using a type of Tetrahedron Mesh with a size of 17mm obtained by

Each computing result as shown in table 6.

TABLE 6.
VALUE DISTRIBUTION OF VON MISES STRESS AT 55° PITCH ANGLE.

| Degree	55°			
Condition	WC1C	WC2C	WC3C	WC4C
Thickness	25mm	35mm	40mm	50mm
Nodes	21916	22456	23302	25497
Element	80047	84570	89116	100788
Index	Value (N/m²)	Value (N/m²)	Value (N/m²)	Value (N/m²)
10	2.88E+08	2.01E+08	1.84E+08	1.36E+08
9	1.34E+08	9.96E+07	9.13E+07	6.93E+07
8	6.27E+07	4.94E+07	4.54E+07	3.53E+07
7	2.93E+07	2.45E+07	2.26E+07	1.80E+07
6	1.37E+07	1.21E+07	1.12E+07	9.14E+06
5	6.37E+06	6.01E+06	5.57E+06	4.65E+06
4	2.97E+06	2.98E+06	2.77E+06	2.37E+06
3	1.39E+06	1.48E+06	1.37E+06	1.20E+06
2	6.48E+05	7.31E+05	6.83E+05	6.13E+05
1	3.02E+05	3.62E+05	3.39E+05	3.12E+05
0	1.41E+05	1.80E+05	1.69E+05	1.59E+05
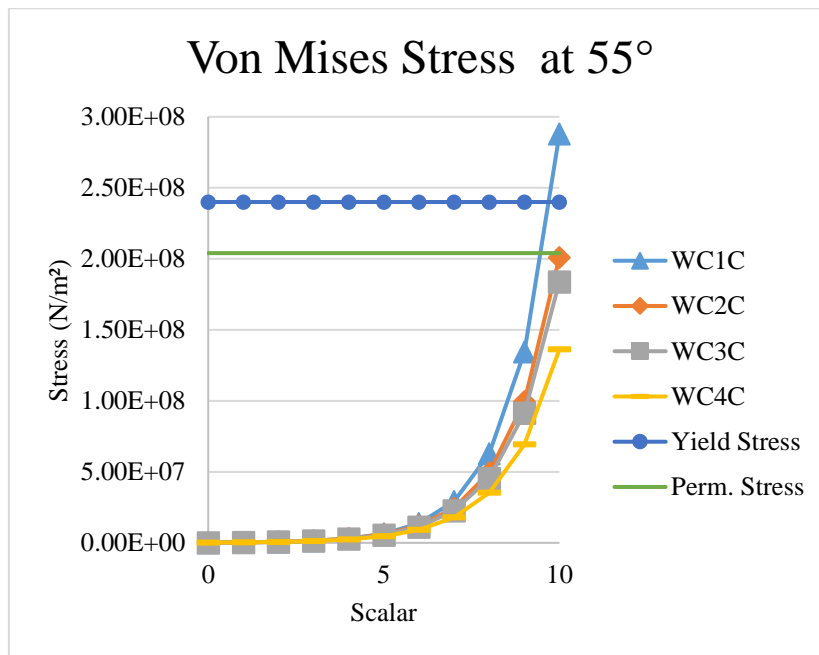
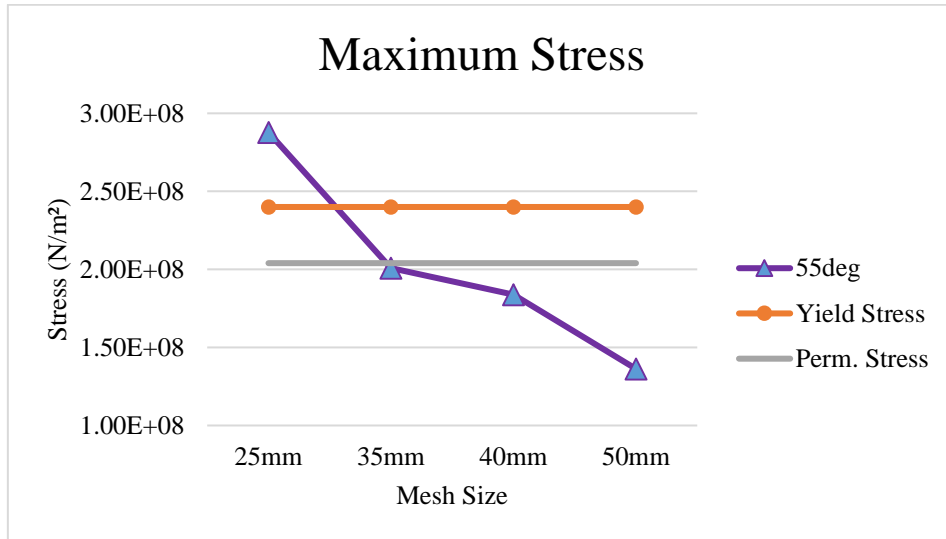**Figure 27.** Von Mises Stress result at 55° pitch angle.

Figure 28. Maximum Von Mises Stress at 55° pitch angle.

From the results of computations with a pitch 55° angle, we can obtain that the material included in the allowable stress category is 35mm thick with a voltage of 2.01E+08 N/m², 40mm thick with a maximum voltage of 1.84E+08 N/m², and thick 50mm with a maximum of 1.36E+08 N/m².

4) Design Voltage Analysis Study

Computing varied from several working conditions above shows the difference in results seen from the maximum stress obtained. In order to simplify the overall analysis, it is presented in the graph below:
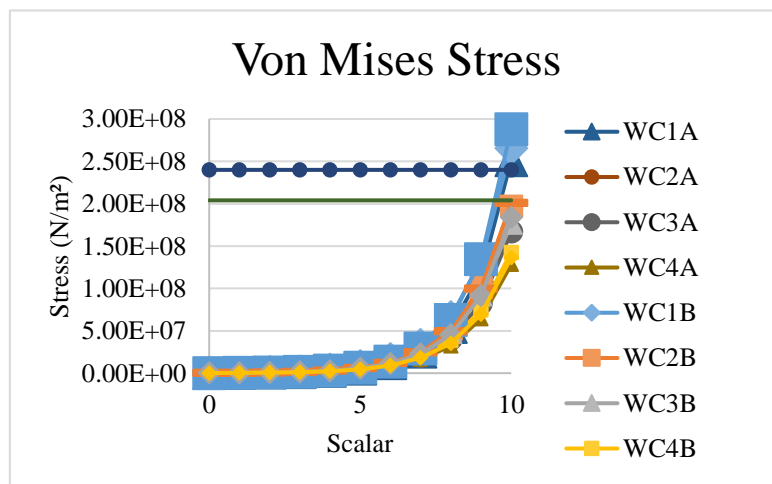

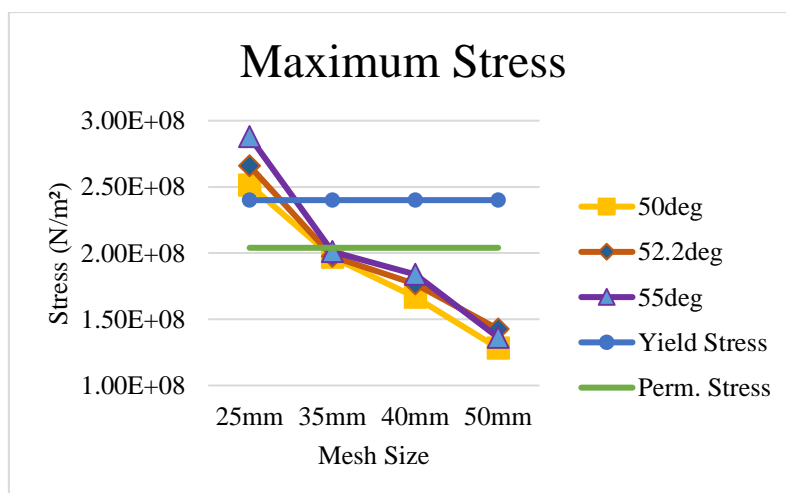**Figure 29.** Von Mises Stress results.

Figure 30. Maximum Von Mises Stress

Looking at the graph above, what is not included in the allowable stress category is the angle of 50° 25mm thick with a maximum voltage of 2.51E+08 N/m², angle 52.5° 25mm thick with a maximum voltage of 2.66E+08 N/m², angle 55° 25mm thick with a maximum voltage of 2.88E+08 N/m².

IV. CONCLUSION

From the results of calculations and computations that have been done, the writer can draw conclusions:

Design of Cutter Head brief as below:
a. The ability of the Cutter Head is designed to operate within 8m with the ability to dredging on Soft soil material with estimated material found namely Salt, Coarse-grained, Fossiliferous limestones, Altered Igneous Rock, Claystones, and Coal. The medium with the estimated material found is (Marlstones, Limestones, Marble, Shales, Phyllites, Highly Micaceous Schists, Altered Intrusive Igneous Rocks, and altered Metamorphic Rocks). Material stress strength is estimated to work at a relatively soft density of <100 Mpa and for Medium around 100 Mpa - 170 Mpa.
b. The Blade Cutter design of Figure design has a slope angle of 52.5 ° with a cross-section of 35 mm thickness, the width of 126 mm, has maximum stress 197 N/mm² and that value below the permissible stress 204 N/mm².
c. With a crown, there are 5 Blades Cutter with 5 mounting on each blade, having a 1,000 mm diameter geometry with a minimum power circular rotor needed is 9.34 kW.

The stress of the cutter blade is influenced by the thickness and angle of the pitch.
a. The cutter blade design is within 5 cross-sections, 5 force distributions in each blade, the given force is 5,950 N, and the area of each blade is 152.97 mm².
b. The design of the cutter blade is not intended to break hard rock because to break hard rock requires a force of approximately 3 tons or the equivalent of 29,430 N [15].
c. Based on the computational results, if the material has a larger and thicker angle then the smaller the resulting stress is also greater, so to get an acceptable design that the stress design value does not exceed the allowable stress.

d. The cutter teeth are planned to be used in 8m with a prediction of relatively Soft soil material <100 Mpa and for Medium around 100 Mpa - 170 Mpa. The cutter teeth material to be used is the S2 series Stell Alloy which has a hardness value of 440-520 HB and a yield of 1500 N/mm² which is suitable to guarantee the toughness of cutter teeth because the minimum material cutter voltage must be at 40 HRC (Rockwell C Hardness) or 373 HB (Brinell Hardness) or 388 HV (Vickers Hardness) or minimum cutter material voltage of 1265 N/mm² [9].

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