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STRENGTH ANALYSIS OF THE JAW GRIPPER DESIGN USING FILAMENT ONYX-CARBON FIBER REINFORCED MATERIAL

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ABSTRACT

A robot gripper is one of the technologies commonly used to grip an object. Gripper has an arm shape that is adjusted to its function. Gripper with a circular shape that functions to grip the workpiece, but the design of this jaw gripper is still not optimal because it still uses too much material. This research aims to improve the existing jaw gripper design to be more optimal in using materials and costs incurred. In addition, after making design improvements, then conduct a Finite Element Analysis (FEA) based simulation to determine the strength of the design when stressed and also conduct an analysis using Markforged software to find out the difference in part details such as the time required to print, the use of materials and the estimated material costs incurred. The results of the stress analysis simulation Von Mises stress of 13.34 Mpa, Von Mises stress that occurs is categorized as safe because it is below the Yield Strength of 254.1 Mpa. In contrast, the displacement result is 0.014 mm, while the minimum safety factor is 15.

Keywords: *Robot Gripper, Jaw Gripper, Finite Element Analysis, Von Mises Stress, Safety Factor*

1. INTRODUCTION

Developments in the industrial world are moving rapidly and competitively. In the industrial world, it is familiar with the automation process; almost all production processes in an industrial company use the automation process to produce a product quickly in mass quantities with high precision [1].
Robots are now one of the most popular fields in education, industry, and many others. Robot types are usually divided into two, namely, controlled robots and automatic robots [2]. The development in the field of computers and electronics and control is using robots [3]. Various kinds of research in the world of robotics are still being developed to improve the function of robots [4]. The funds spent are considerable because they are used for robot research and development [5]. Robots are designed to assist or replace the role of humans in carrying out heavy tasks such as working in hazardous areas, required to work fast with a high level of precision and consistent with the results. [6]

A robot arm, commonly called a robot manipulator, is a mechanical system shaped like a human arm. Robot arms are widely used to grasp and place objects in predetermined positions. In this case, the gripper is an end effector of a robot arm. Making a robot arm in the industrial world is not cheap and easy because the materials must have high resistance to temperature and pressure and flexible movements. [7]. The shape of the jaw gripper, which is like human fingers, is useful in the process of taking and placing objects. The jaw gripper can be designed to adjust the shape of the workpiece. The jaw gripper is in direct contact with the workpiece to be grasped and functions as a gripper for the object [8].

Problem Formulation

This research aims to know the strength requirements of the finite element analysis, which produces von Mises stress, displacement, and safety factor in the jaw gripper design based on the results of stress analysis simulations. Then analyze the Eiger.io application to find out the material requirements used and the costs incurred. Furthermore, thus, the output of this research is an industrial design.

2. RESEARCH METHOD

The methodology used to conduct the research to find and determine the needs and strength of the jaw gripper starts from finding sources and collecting data by searching for information and studying research related to designing a jaw gripper. Then, identify the problems that occur in the existing jaw gripper design, then analyze the problems that occur in the design, such as too much material used. Then do the calculation to get data to determine the jaw gripper's needs. Next, frame modeling and dimensional adjustments are made using Autodesk Inventor 2021 Student Version software. Then stress analysis testing uses Inventor software with predetermined boundary conditions. The design improvement results can be considered if the safety factor is≥ 4 [9]. If it does not achieve these results, frame modeling and dimensional adjustments must be made again. The next step is to analyze and discuss the stress analysis results. After analyzing and discussing, the results will be obtained, and conclusions can be drawn.

This research uses Autodesk Inventor. Autodesk Inventor is one of the products from Autodesk Inc. Autodesk Inventor simulation is useful for analyzing to prove the strength and validity of a design [10]. The stress analysis performed by Autodesk Inventor uses the finite element analysis method. Finite element analysis is a common method used by structural analysis software. Finite element analysis is a mathematical numerical technique for calculating the strength and structural behavior of engineering components by dividing objects into a mesh shape or what is commonly called a mesh [11]. Then proceed with simulating the Eiger.io application to find out the material requirements used and the costs incurred.

3. RESULTS AND DISCUSSIONS

3.1 Gripping force calculation analysis

The gripping force calculation analysis is carried out to determine the gripper's need to grip the workpiece. The gripper grips the workpiece one by one.

Force formula:

$\sum f : m\ x\ a$ .... (1)

Where Σf is the resultant force, m is the mass (kg), and a is the acceleration $(m/s)^2$

$f_n - w = ma$ .... (2)

Where fn is Normal force, w is mass (N), m is mass (kg), and a is acceleration $(m/s)^2$

n.μ.gf - mg = ma.. (3)

Where μ is the coefficient of friction, gf is gripping force (N), m is mass (kg), g is gravity (m/s^2), and a is acceleration $(m/s)^2$

Equations (1), (2), and (3) will be inputted into equation (4) to get the result of the gripping force.

$gf = \frac{m\,(g+a)}{n \times \mu}\ x\ sf$ .... (4)

Where gf is the gripping force of one jaw (N), m is the mass of the workpiece (kg), g is gravity (9.81 m/s²), a is acceleration (m/s²), n is the number of arms, μ is the coefficient of friction, and sf is the Safety factor.
Before calculating the gripping force, calculations are needed to find the acceleration given by the robot to the gripper. The following calculations are required:
Calculations using the formula for straight-line motion

$$s = v_0 \times t + \frac{1}{2} \times a \times t^2 \quad (5)$$

Where s is the distance (m), v0 is initial velocity (m/s), t is time (s), and a is acceleration (m/s²).
Specifications of the *jaw gripper* to find *gripping force* and moment can be seen in Table 1.

Table 1. Specifications of the *jaw gripper.*

No.	Description	value
1	Distance (m)	0,277750
2	Time (s)	2,74
3	Mass (kg)	0,388
4	Acceleration (m/s²)	0,0725
5	Coefficient of friction	0,3
6	*Safety Factor*	2

By solving to find acceleration by using equation (5), the result is 0.0725 m/s²
After obtaining the acceleration results, calculate the *gripping force* using equation (4); the data obtained from the calculation of the *gripping* force is 12.791 N.

3.2 Moment and Force Analysis

The moment of force is the reverse effect that a force produces on the object being acted upon. The moment of a force is equal to the product of the force and the perpendicular distance from a point [12].

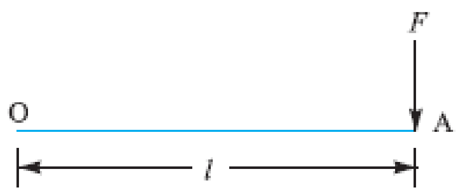

Figure 1. Moment and Force

$$M = F \times l \quad (6)$$

M: Moment of Force (Nm)

F: Force of action on the object (N)
l: Perpendicular distance from point O to the force (F)

Three moments occur in the gripper: the x-axis moment, the y-axis moment, and the z-axis moment. The calculation of the gripper moment can be seen below:

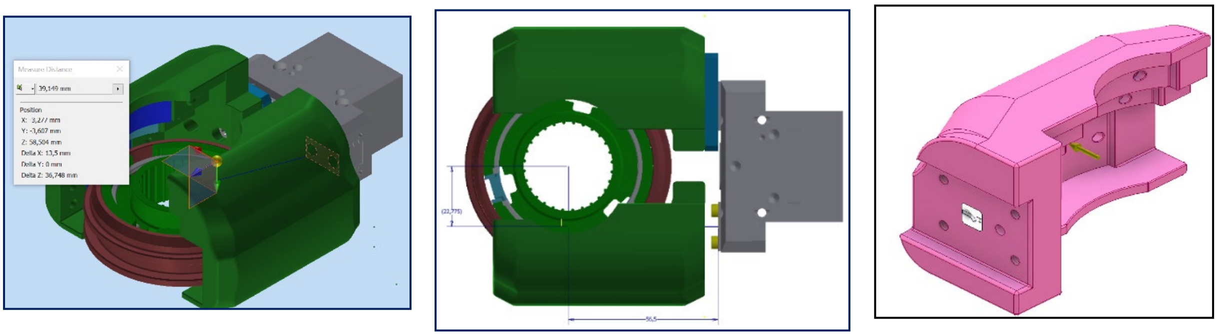

Figure 2. Left moment Mx and Mz, center moment My, and constraints and loads

1. The x-axis moment (Mx) of total weight with gripper distance to *gripping force* (horizontal).
$Mx = wtot \times L \times gf$
Description Mx is Axis moment x (Nm), Wtot is total weight (kg), L is Distance (m), gf is *Gripping Force (*N)
solving the calculation of the moment of force M x
Mx = 0.592 kg × 0.039149 m × 12.757N
Mx = 0.295 Nm

2. Y-axis moment (My) *gripping force* with *gripper* distance.
$My = gf \times L$
Description My is y Axis Moment (Nm), gf is *Gripping Force* (N), L is the distance (m)
Completion of the calculation of the moment of force My:
M =y 12.757N × 0.0565m
My = 0.721 Nm

3. Z-axis moment (Mz) total weight with gripper distance to gripping force (vertical).
$Mz = wtot \times L \times gf$
Where Mz is the z Axis Moment (Nm), Wtot is the total weight (Kg), L is the distance (m), and gf = Gripping Force (N).
calculation of the moment of force M x
Mx = 0.592 kg × 0.036478 m × 12.757N
Mx = 0.275 Nm

3.3 Jaw Gripper Analysis with Finite Element Analysis (FEA) Method

Simulation of jaw gripper testing on the OP 30 Input gear shaft is carried out by providing constraint points, loading of 180N, and conducting static and homogeneous testing. Data processing on the assembly is carried out before analyzing the assembly. The data processed is in the form of adding Onyx-Carbon Fiber Reinforced material [13] and meshing settings by default where average element size 0,100, minimum element size 0,200, and grading factor 1,500 with the number of nodes 70761 and elements 46057. The physical properties of materials used in stress analysis with Autodesk Inventor 2021 Student Version can be seen in Table 2, constant and loads from Figure 2, and the results of simulations using Autodesk Inventor can be seen in Figure 3, Figure 4, and Figure 5.

Table 2: Physical Properties of Onyx Material (Ghebretinsae, 2019)

Material	Onyx-Carbon Fiber Reinforced
Young's Modulus	25040 Mpa
Poisson's Ratio	0,30 ul
Density	1,4 g/cm^3
Yield Strength	254,1 Mpa
Tensile Strength	470,5 Mpa

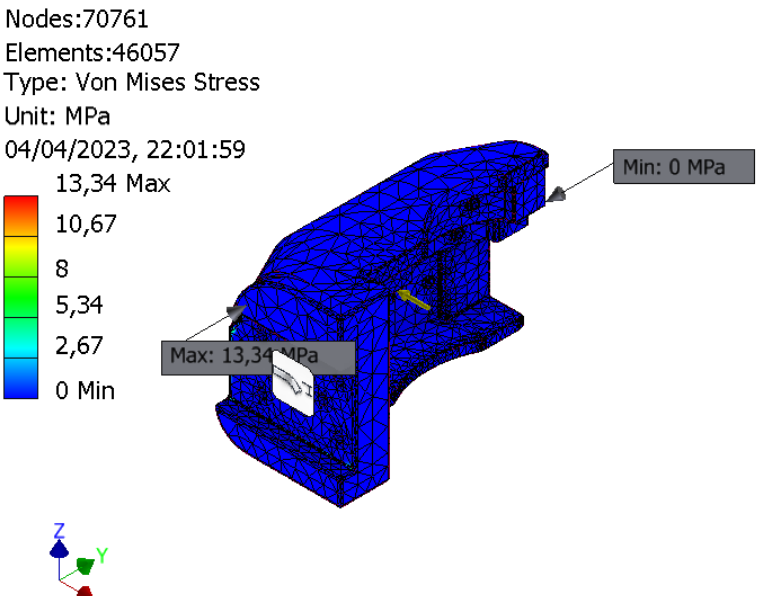

Figure 3. Von Mises Stress Analysis Results of Jaw Gripper

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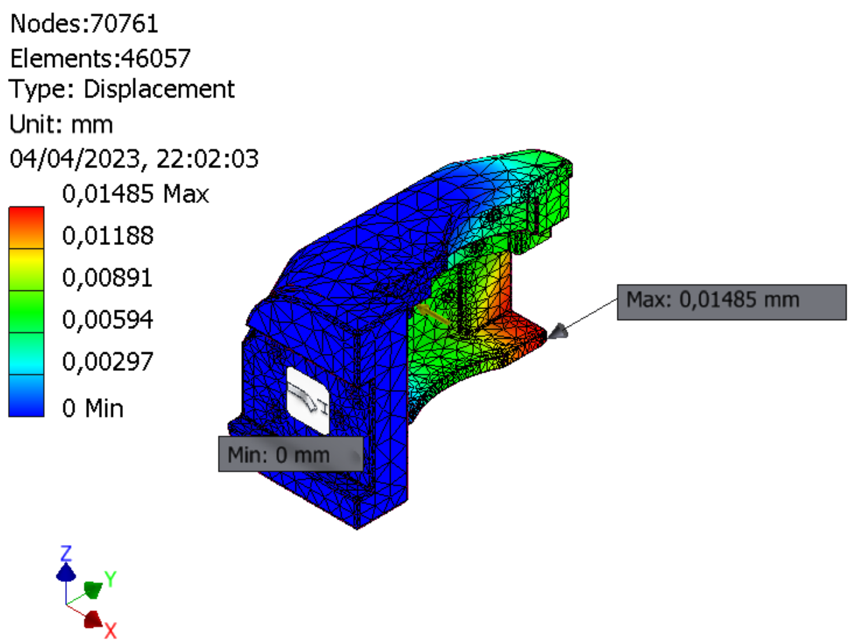

Figure 4. Jaw Gripper Displacement Analysis Results

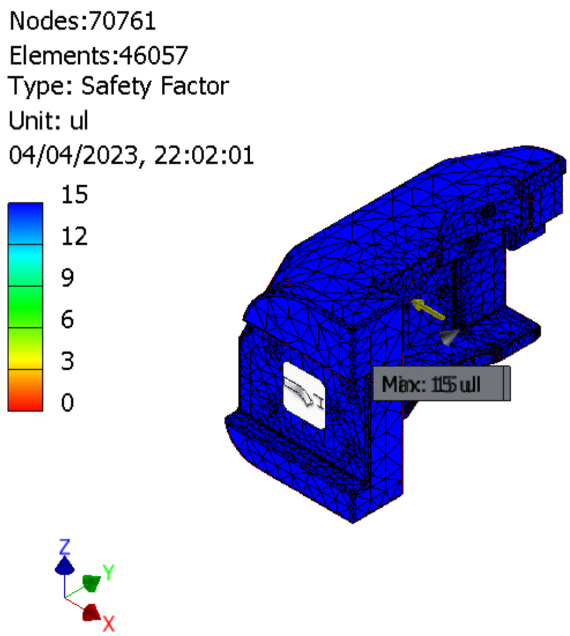

Figure 5. Jaw Gripper Safety Factor Analysis Results

The jaw gripper strength analysis results are Von Mises stress, displacement, and Safety Factors values. The material used in the simulation is an Onyx-Carbon Fiber Reinforced filament. The simulation results are described in Table 3 below:

Table 3. Result of Stress Analysis

Result	Design Jaw Gripper	
	Minimum	Maximum
Von Mises Stress (MPa)	0 Mpa	13,34 Mpa
Displacement (mm)	0	0,01485 mm
Safety Factor (ul)	15	15

The maximum value of Von Mises Stress in the jaw gripper design is 13.34 Mpa. The Von Mises Stress that occurs is categorized as safe because it is below the Yield Strength of 254.1 Mpa [14] displacement value of 0.01485 mm. Displacement is classified as safe because it is relatively small, and the Safety Factor value is 15.

3.4 Jaw Gripper Analysis Using Software Eiger.io

After performing the jaw gripper design and simulating Finite Element Analysis, a simulation is carried out using the Eiger.io application to know the number of material requirements and the estimated costs incurred by the Eiger.io software for the simulation results can be seen in Figure 6 and Table 4.

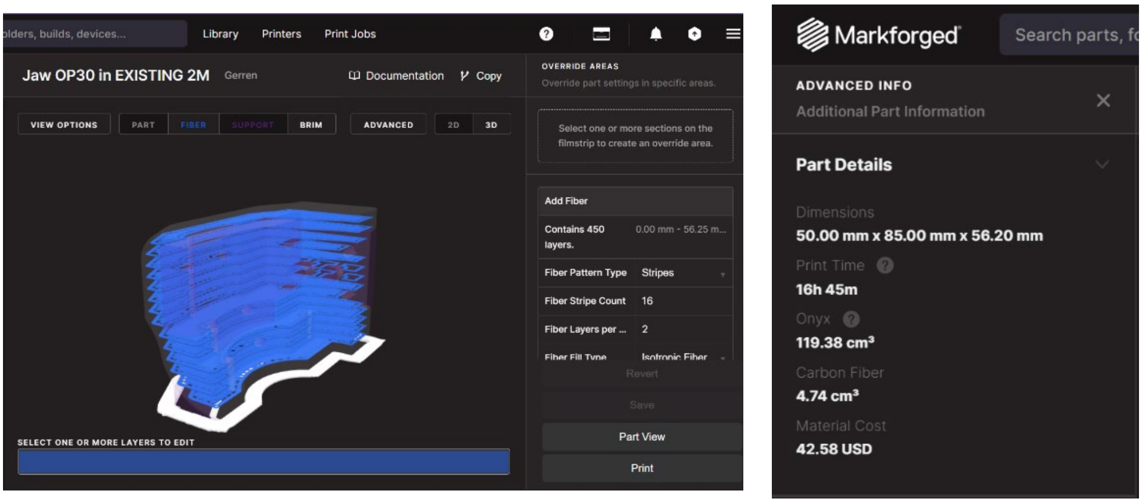

Figure 6. Part details Jaw Gripper

Table 4. Analysis results using Eiger.io *software*

Part Detail	Result
Dimensions (mm)	50 x 85 x 56.20
Print Time	16 hours 45 minutes
Onyx (cm^3)	119.38
Carbon Fiber (cm^3)	4.74
Material Cost (USD)	42.58

The data that can be taken from simulations using the software Eiger.io is the time required for the printing process of 16 hours 45 minutes using onyx material 119.38 cm^3 and carbon fiber 4.74 cm^3 with an estimated cost of 42.58 USD.

4. CONCLUSIONS AND SUGGESTIONS

conclusions

Based on the Stress Analysis simulation results, the data obtained from the simulation of the jaw gripper design Von Mises stress of 13.34 Mpa, the Von Mises Stress that occurs is categorized as safe because it is below the Yield Strength of 254.1 Mpa. In contrast, for the Displacement result of 0.01485 mm, while the minimum Safety Factor result is 15, for the simulation results using the Eiger.io application display the results during the print process for 16 hours 45 minutes using Onyx and carbon fiber materials as much as 119.38 cm3 and 4.74 cm3 and an estimated cost of 42.58 USD. From the simulation data results, the jaw gripper design can be categorized as overkill and not optimal, so it can still be redesigned to get optimal design results.

Suggestions

If you find a case where a jaw gripper design is inefficient in the use of materials, it can be made with a very minimal design in the use of materials. If the results of a design that uses very minimal materials are not yet strong, then a design is needed using materials in the medium category until you find the optimal design. In future research, it is expected to redesign the jaw gripper.

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