Stress Distribution Analysis of the Rectangular and Star-Blade for Plastic Crusher Machine Using Finite Element Analysis

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Abstract. Recycling plastic waste can help reduce plastic waste, which is the world's largest problem. The first solution is a plastic crusher machine, which converts plastic packaging into pellets, especially for plastics made from polyester, which is often used in bottle packaging. An integral part of the crushing machine is the crushing blade, which determines the design and analysis of the blade. The finite element analysis method is widely used in engineering analysis. Its results can provide useful information for the analysis of manufacturing processes. A rectangular blade and a star-shaped blade are the two types to consider. The analytical results obtained on the blade of the crusher machine in the rectangular shape that was given loads by 200 N, 400 N, and 600 N are 1.285 x 10⁻⁶ N/m², 2.570 x 10⁻⁶ N/m², and 3.855 x 10⁻⁶ N/m², respectively. We obtained the displacements are 1.080 x 10⁻⁶ mm, 2.160 x 10⁻⁶ mm, and 3.241 x 10⁻⁶ mm, respectively. The maximum von mises stress result on consecutive star-shaped blades are 8.890 x 10² N/m², 1.778 x 10³ N/m², and 2.667 x 10³ N/m². The displacement obtained are 1.211 x 10⁻⁶ mm, 2.422 x 10⁻⁶ mm, and 3.633 x 10⁻⁶ mm. The results of this analysis indicate that for the star blade, the shape is better than for the rectangular blade at the same time, and for the star blade, the stress is smaller than for the rectangular blade. Based on this simulation, the safety factor is 15, which means that it is more than 1, which means that it is safe.

Keywords: Displacement, Von misses stress, Blade shape, Finite element analysis, the Safety factor

1. Introduction
Indonesia has high biodiversity and coral reefs. Unfortunately, Indonesia is estimated to be the second-largest contributor to ocean plastic pollution after China [1]. PET (Polyethylene terephthalate) is a plastic material used for making bottles, this material is widely accepted because it has advantages such as being disposable, cheap, and lightweight. Plastic crusher machine serves to destroy or change plastic bottles into smaller pieces that can be recycled into new products [2]. The blade is one of the most important components in a plastic crusher machine, the suitability of the design in its various variations greatly affects the durability or the results of the crusher machine [3]. Finite element
analysis (FEA) is one of the techniques of the Finite Element Method, this technique can analyze a design, with a CAE program such as Abaqus. This technique has advantages such as reducing the number of design prototypes produced [4]. This method can also see the results of von mises stress, deformation, and fluid flow to heat transfer in the design, to optimize the design [5]. The renewal and purpose of this research are to determine and compare which two blade shapes have good resistance by looking for the von misses stress and displacement of the two shapes.

2. Method
The research aims are to compare the two blades, rectangular and star-shaped. The modeling of the two blades design was carried out using CAD (Computer-Aided Design). Rectangular blade and star blade design modeling is attached in Figure 1. CAD method using Autodesk Inventor

![Figure 1. (a) Rectangular blade design, (b) Star blade design make by Autodesk Inventor](image)

2.1 Finite Element Analysis
The way FEA works is by dividing objects that have been designed into finite small parts or commonly called meshing. These small parts will be analyzed and the results will be combined again to get the overall results of the objects that have been designed. FEA can be used to find von mises stress, displacement, and even heat transfer [6]. In this research, FEA will be used to find von mises stress and displacement, here also using tetrahedral type meshing [7]. The meshing application is attached in Figures 2. FEA method using Abaqus program and Autodesk Inventor

![Figure 2. (a) Meshing in rectangular blade, (b) Meshing in Star Blade make by Autodesk Inventor](image)

The meshing obtained from the CAE program has 1336 nodes on the rectangular blade, while the star blade has 3226 nodes. The elements contained in the rectangular blade are 639, while for the star blade there are 1868 elements.

2.2 Von Mises Stress and Displacement
Von mises stress calculation on the elements of Finite Element Analysis given by
Where $E$ is the young modulus for each material used in the blade design, and $\varepsilon$ is the strain within each design [8]. The strain itself is found from displacement

$$\varepsilon = \frac{\Delta l}{l_0} = \frac{l-l_0}{l_0}$$  \hspace{1cm} (2)

Where $\Delta l$ is the difference between the total length and the initial length of the geometry of each design [9].

### 2.3 Safety factor

Safety factor It is a factor of the ability of an object when it receives a load that has been determined from the outside, this load can be compressive or tensile [10]. The safe value for the safety factor itself is 1, if the safety factor value obtained is less than one, then the design is considered unsafe [11].

$$Safety \ factor = \frac{\sigma_{Maximum}}{\sigma_{Allowable}}$$  \hspace{1cm} (3)

Where $\sigma_{Maximum}$ is the maximum stress that a design or object can fracture, while $\sigma_{Allowable}$ is the stress that is allowed in a material [12]. Each material has a different allowable stress [13].

### 3. Result and Discussion

Following are the results of the von mises stress and displacement in both blade shapes. The analysis was carried out using the CAE program, called Abaqus. Abaqus can be used for complex analytical modeling, analysis, monitoring and visualizing simulation.

#### 3.1 Von mises stress

The process is analyzed with the load magnitude, the load magnitude is 200 N, 400 N, and 600 N. Given different magnitudes to know the stress distribution of the blades in different load magnitudes.

#### 3.1.1 Rectangle Blade Shape

The following is an analysis of the von mises stress on a rectangular blade, given a load of 200N, 400N, and 600N. The analysis results are attached in Figure 3, Figure 4, and Figure 5

**Figure 3.** Result of rectangle blade analysis at 200 N load
The maximum result that occurs in a rectangular blade at 200 N load is $1.285 \times 10^{3}$ N/m² and the average von mises stress is $6.764 \times 10^{2}$ N/m². The maximum result at a load of 400 N is $2.570 \times 10^{3}$ N/m² and the average stress is $1.353 \times 10^{3}$ N/m². The maximum result at a 600 N load is $3.855 \times 10^{3}$ N/m² and the average stress is $2.029 \times 10^{3}$ N/m².

3.1.2 Star Blade Shape
The following is an analysis of the von mises stress that occurs in a star blade, given a load of 200N, 400N, and 600N. The analysis results are attached in Figure 6, Figure 7, and Figure 8.
The maximum result that occurs in a rectangular blade at 200 N load is $8.890 \times 10^2$ N/m$^2$ and the average von mises stress is $4.447 \times 10^2$ N/m$^2$. The maximum result at a load of 400 N is $1.778 \times 10^3$ N/m$^2$ and the average stress is $8.894 \times 10^2$ N/m$^2$. The maximum result at a 600 N load is $2.667 \times 10^3$ N/m$^2$ and the average stress is $1.334 \times 10^3$ N/m$^2$.

### 3.2 Displacement

The process is analyzed with a load magnitude, as the load to be pressed by the blade, the magnitude is 200 N, 400 N, and 600 N. Given different magnitudes to know the distribution of deformation that occurs the star blade and rectangle blade under different load magnitudes.

#### 3.2.1 Rectangle Blade Shape

The following is an analysis of the displacement that occurs in a rectangular blade, given loads of 200 N, 400 N, and 600 N. The analysis results are attached in Figure 9, Figure 10, and Figure 11.
The maximum result that occurs in a rectangular blade at 200 N load is $1.080 \times 10^{-6}$ mm and the average displacement is $5.401 \times 10^{-7}$ mm. The maximum result at a load of 400 N is $2.160 \times 10^{-6}$ mm and the average is $1.080 \times 10^{-6}$ mm. The maximum result at a 600 N load is $3.241 \times 10^{-6}$ mm and the average is $1.620 \times 10^{-6}$ mm.

3.2.2 Star Blade Shape
The following is an analysis of the displacement that occurs in a rectangular blade, given a load of 200N, 400N, and 600N. The analysis results are attached in Figure 12, Figure 13, and Figure 14.
The maximum result that occurs in Star Blade at 200 N load is $1.211 \times 10^{-6}$ mm and the average displacement is $6.050 \times 10^{-7}$ mm. The maximum result at a load of 400 N is $2.422 \times 10^{-6}$ mm and the average displacement is $1.211 \times 10^{-6}$ mm. The maximum result at a 600 N load is $3.633 \times 10^{-6}$ mm and the average is $1.817 \times 10^{-6}$ mm.

3.3 Blade Shape Comparison

After analyzing using the CAE program, the comparison of the two-blade shapes will be compared between the maximum value and the average value that occurs in each design. The following is the attachment in table 1,2,3 and 4.
Table 1. Comparison of Average Von Mises Stress

| Load | Rectangular Blade | Star Blade |
|------|-------------------|------------|
| 200N | $6.764 \times 10^2$ N/m² | $4.447 \times 10^2$ N/m² |
| 400N | $1.353 \times 10^3$ N/m² | $8.894 \times 10^2$ N/m² |
| 600N | $2.029 \times 10^3$ N/m² | $1.334 \times 10^3$ N/m² |

Table 2. Comparison of Maximum Von Mises Stress

| Load | Rectangular Blade | Star Blade |
|------|-------------------|------------|
| 200N | $1.285 \times 10^3$ N/m² | $8.890 \times 10^2$ N/m² |
| 400N | $2.570 \times 10^3$ N/m² | $1.778 \times 10^3$ N/m² |
| 600N | $3.855 \times 10^3$ N/m² | $2.667 \times 10^3$ N/m² |

Table 3. Comparison of Average Displacement

| Load | Rectangular Blade | Star Blade |
|------|-------------------|------------|
| 200N | $5.401 \times 10^{-7}$ mm | $6.050 \times 10^{-7}$ mm |
| 400N | $1.080 \times 10^{-6}$ mm | $1.211 \times 10^{-6}$ mm |
| 600N | $1.620 \times 10^{-6}$ mm | $1.817 \times 10^{-6}$ mm |

Table 4. Comparison of Maximum Displacement

| Load | Rectangular Blade | Star Blade |
|------|-------------------|------------|
| 200N | $1.080 \times 10^{-6}$ mm | $1.211 \times 10^{-6}$ mm |
| 400N | $2.160 \times 10^{-6}$ mm | $2.422 \times 10^{-6}$ mm |
| 600N | $3.241 \times 10^{-6}$ mm | $3.633 \times 10^{-6}$ mm |

3.4 Safety Factor

This research uses a compressive load with a maximum value of 1000N. The CAD program reads both blade shapes having a safety factor value of 15, attached to Figure 15 and Figure 16.

Figure 15. Safety Factor Rectangular Blade shape
4. Conclusion
The results of the analysis conducted using CAD and CAE programs found that the blade had increased von mises stress and displacement on a load 200N, 400N, and 600N. Rectangle blade has a spread of von mises star higher than the blade, with the highest value is $3.855 \times 10^3$ N/m$^2$ while the highest value that occurs in the star blade is $2.667 \times 10^3$ N/m$^2$. Areas of high concentration (red color) are classified as few in both blade designs. The star blade has a higher displacement value than the rectangle blade, the maximum value is $3.663 \times 10^6$ mm, and the maximum value of the rectangle blade of $3.241 \times 10^6$ mm. The difference in the displacement of the two blades is small so it can be concluded that the two blades have almost the same displacement value. The displacement that occurs in both blades is close to 0 so it can be ignored, and there is no significant deformation. The design of these two blades has a relatively safe factor, with a 1000N load, a safety factor of 15 is found, this value is more than 1, which means that the blade design is safe for crushing plastic.

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