**The present work was submitted to the Faculty of Engineering**

# IMPROVEMENT OF EFFICIENCY OF WOOL SHREDDER

**Bachelor Thesis**

by

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Ulaanbaatar/Nalaikh, 05/01/2023

## Statutory Declaration

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I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis

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I did not use any sources other than those stated. In case the work is additionally submitted on a data medium, I declare that the written and the electronic form are entirely identical. The work was not submitted in the same or similar form to any examination authority.

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# Abstract

The main objective of this thesis is to examine the current performance of a wool shredding machine and to increase potential improvements that could enhance its efficiency and capacity. Despite the constraints that limitations to the existing machine for example frame of the machine, rotor diameter, bearing, and shredding chamber size, this study identifies and explores various restrictions within these parameters.

The thesis will cover the knowledge and information about wool pellets, types and properties of wool as well as shredding machine parts and their function. Also influencing factors on efficiency of the shredding process were studied.

The research finds some limitations and possible developments. Possible developments have the transitioning from a single shaft shredding machine to a double shaft shredding machine could offer significant performance advantages.

This study contributes to the existing body of knowledge on wool shredding machines and covers the way for future innovation in this field.

# Acknowledgements

First and foremost, I would like to express my deepest appreciation to all those who provided me the possibility to complete this thesis. I would like to thank my thesis advisor, Odbileg.N, whose expertise, understanding, and patience, added considerably to my graduate experience. Your guidance and encouragement were invaluable.

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Lastly, I would like to thank my fellow classmates, friends and my family for their understanding and endless love throughout my studies.

# 1. Introduction

## 1.1 Background

Wool is the textile fiber obtained from sheep and other animals, especially goats, rabbits, and camelids. (1) Being extensively utilized in the textile industry, wool stands as one of the most prevalent natural fibers. This industry is recognized as one of the largest and rapidly expanding sectors worldwide. It is widely used in the production of high-quality clothing, blankets, garments, textiles, carpets,insulation and gardening industries due to its natural warmth, softness, and durability. Wool has long been accepted as an environmentally positive fiber choice with a number of benefits, such as being renewable, biodegradable, recyclable and safe. It has a naturally high UV protection, which is much higher than most synthetics and cotton. As an animal fiber, wool consists of protein together with a small percentage of lipids. This makes it chemically quite distinct from cotton and other plant fibers, which are mainly cellulose.

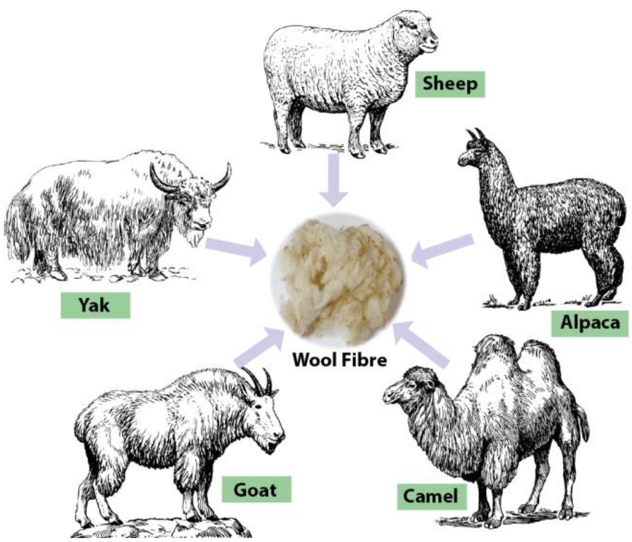


Figure 1. Wool fiber from different animals

Figure 2. Wool fiber

The production process of woolen products involves various stages, including shearing, cleaning, carding, and shredding. In the production process of woolen products, the wool shredding machine plays a crucial role in producing high-quality wool fibers that are suitable for further processing. There are two basic parts to a wool shredding machine. The first is a part for shredding, while the second is for pressing. In this study, we mainly focus on the shredding part of the wool shredding machine. A wool shredder machine is a device that can shred wool and wool fibers into smaller or shreds.

Wool production takes place in a number of areas of the world. Wool production can be the production of keratin fibers from a range of animals. This can include the production of cashmere, alpaca, mohair, angora, yak, elk, and camel fiber. Fiber characteristics from sheep wool can vary depending on the sheep breed, the environmental grazing conditions, its age and export opportunities for the country of origin (12).

| Fiber | Tonnes (million) | Percentage on market (%) |
|---|---|---|
| Polyeester | 55.1 | 51.5 |
| Cotton | 26.1 | 24.4 |
| Cellulosic | 6.7 | 6.2 |
| Other plant fibers | 6.1 | 5.7 |
| Polyamide | 5.4 | 5 |
| Other manmade | 6.1 | 5.7 |
| Wool sheep | 1.1 | 1 |
| Wool other animals | 0.05 | |
| Silk | 0.16 | 0.1 |
| Feathers down | 0.32 | 0.3 |
| Total | 107 | 99.9 |

Table 1. World supply of textile fibers (12)

## 1.2 Problem statement and research question

In general, wool shredding machines still face some challenges such as low production rates, high energy consumption, and increased wear and tear of machine components. However, the current wool shredding machines available in the market are often inefficient and require frequent maintenance and it is leading to increased downtime and decreased productivity.
Our current wool shredding machine has several problems. To begin with the shredding process, there were such problems which are related to the feed rate and productivity of the wool shredding process. For example: the risk of clogging the machine and thus stacking a movement of shredding machine.

Therefore, the need for improving the efficiency of wool shredding machines has become increasingly important to the growing demand for high-quality woolen products. Following research questions that are arised:

- What are the factors that affect the efficiency of a wool shredder?
- How can these factors be optimized to increase productivity?
- How do different types of shredding blades affect the efficiency of wool shredding machines?
- What is the optimal combination of operational parameters (such as speed, torque, and feed rate) for maximizing the efficiency of wool shredding machines?
- How can the design of wool shredding machines be optimized to improve their efficiency?
- What is the economic feasibility of investing in more efficient wool shredding machines, and what are the potential cost savings?
- How can the productivity of the product be improved through process improvements in wool shredding?
- What are the limitations of existing research on improving the efficiency of wool shredding machines, and how can these limitations be addressed in future studies?

These research questions can lead to the methodology, data collection, and analysis of a study on improving the efficiency of wool shredding machines.

## 1.3 Objective and significance of the study

The research will focus on two main areas: evaluating the wool fertilizer machine and increasing the efficiency of the wool shredder. In first main tasks have:

- Determine evaluation criteria
- Test and evaluate the wool fertilizer machine
- Finish drawings of the machine
- Analyze shredder cases by FEA.

Second main task was most important in this study for including:

- Calculate cutting force of the per blades
- Determine optimal hardness of blades
- Determine efficiency of the shredder

Literature study is carried out based on existing shredder machines, and field research observes the calculation and factors that affect their efficiency.

The significance of this research lies in improving the efficiency and productivity of current existing shredding machines.
First, wool shredding is an essential process in the production of woolen products, and improving the efficiency of this process can help to reduce the cost of production, increase the productivity rate, and improve the quality of the product.

Second, as the demand for high-quality woolen products increases, it is important to find ways to meet this demand while maintaining the sustainability of the industry. Improving the efficiency of wool shredding machines can help to reduce the environmental impact of wool production by reducing energy consumption and waste generation.

Third, this study can contribute to the broader field of mechanical engineering by providing insights into the design and optimization of shredding machines. The findings of this study can be used to develop more efficient and effective shredding machines for other applications beyond wool shredding.

Overall, we aim to explore the potential of improving the efficiency of wool shredding machines by analyzing their existing design and identifying possible areas for improvement. We will conduct a thorough analysis of the existing literature on wool shredding machines and their operation, along with a comprehensive study of the factors that affect their efficiency. We will also review the latest technological advancements in the field of wool shredding machines to identify potential solutions for improving their efficiency.

# 2. Literature review

## 2.1 Overview of wool and wool shredder technology

### 2.1.1 Why is the wool pellet important?

Wool pellets are an eco-friendly and sustainable option as they are derived from entirely natural and raw wool. They possess organic qualities and are environmentally and climate friendly. With the ability to retain up to 20% of their weight in water, they assist in reducing the frequency of watering. When watered, the wool pellets expand, enhancing the soil's porosity, thereby promoting optimal root growth. This expansion also eliminates the requirement for additives like Perlite.

The purpose of our product is to minimize waste and promote nutrient recycling. We repurpose underappreciated wool by transforming it into wool pellets. Our pellets consist of a single ingredient: 100% raw wool. By converting the nutrient-rich wool into pellets, it becomes convenient to incorporate them into flowerpots and gardens. Another advantage of pelletizing the wool is that, as the pellets absorb water and naturally decompose, they create empty spaces in the soil. This process enhances soil porosity, fostering an oxygen-rich environment.

Wool pellets take six months to break down, slowly releasing nitrogen and other nutrients into the soil, acting as a slow release fertilizer. To support plant growth, the soil requires essential nutrients such as nitrogen, phosphorus, potassium, and other microelements. In contrast, wool fertilizers possess significant amounts of these nutrients, with nitrogen content reaching up to 10% and potassium up to 6%. Additionally, due to its fluffy nature, wool can absorb water that is 3.5 times its weight. Essentially, wool functions as a micro-hydro accumulator, collecting water during periods of high humidity and gradually releasing it to irrigate the soil during drought conditions. This process ensures that the plants receive a continuous water supply for a duration of 10 months, preventing water shortages, while also preventing overhydration as excess water is effectively managed. Furthermore, the soil is aerated as it contracts, allowing for proper water distribution. (3)

Figure 3. Wool pellet

## 2.1.2 Property of wool

Sheep produce various types of wool, each having unique characteristics such as strength, thickness, staple length, and impurity levels. Following figure shows which part of the sheep's body is fine.

| **Common Name** | **Part of Sheep** | **Style of Wool** |
|---|---|---|
| Fine | Shoulder | Fine, uniform and very dense |
| Near | Sides | Fine, uniform and strong |
| Downrights | Neck | Short and irregular, lower quality |

| | | |
|---|---|---|
| Choice | Back | Shorter staple, open and less strong |
| Abb | Haunches | Longer, stronger staple |
| Seconds | Belly | Short, tender, matted and dirty |
| Top-not | Head | Stiff, very coarse, rough and kempy |
| Brokes | Forelegs | Short, irregular and faulty |
| Cowtail | Hindlegs | Very strong, coarse and hairy |
| Britch | Tail | Very coarse, kempy and dirty |

Table 2. Wool fineness (1)

The following are physical properties of wool. There are:

- Tensile strength: In dry conditions is 1-1.7, In wet conditions is 0.8-1.6
- Elongation at break: Standard elongation is 25-35% and 25-50% in wet condition
- Specific gravity: 1.3-1.32
- Moisture regain: Standard moisture regain is 16-18%
- Resiliency: Wool is highly resilient and comes to its original shape when hanged after wrinkled or created.
- Strength: It is stronger than silk. When wet wool loses about 25% of its strength. The longer the fiber the greater will be the strength of the yarn.
- Stretchability: Wool is highly elastic. It is about 10 to 30% stretched when dry and 40 to 50% when wet upon receiving pressure upon drying it readily regains its original dimensions.

- Shrink-ability: Wool is resistant to shrinkage. However long exposure to moisture may cause shrinkage (9).

| Fiber | Density (g/cm3) | Length (mm) | Stiffness/Young's modulus (GPa) | Tensile strength (MPa) | Elongation at break (%) |
|---|---|---|---|---|---|
| Wool | 1.3 | 38-152 | 2.3-5 | 120-180 | 25-50 |
| Cotton | 1.5-1.6 | 10-60 | 4-6 | 264-654 | 3-7 |
| Silk | 1.3 | Continuous | 5-25 | 252-528 | 20-25 |
| Jute | 1.3-1.5 | 1.5-120 | 10-55 | 342-672 | 1.5-1.8 |

Table 3. Comparison of mechanical properties of natural fibers

Yield strength refers to the maximum stress that ductile materials can endure before undergoing permanent shape alteration. On the other hand, tensile strength represents the point at which fracture occurs. Tensile strength measures a material's capacity to withstand being stretched or pulled apart before breaking. Therefore, we will use tensile strength for calculations.

The shear strength of wool fiber is a significant concept. It describes the level of force that can be applied to cut the fiber without causing it to break. (21)

### 2.1.3 Wool shredding technology

Wool shredding technology is the process of reducing raw wool fibers into smaller pieces. The shredded wool can then be further processed into yarn, fabric, or other woolen products.
There are several types of wool shredding machines, each with its own advantages and disadvantages. Some of the most common types include:

1. Blade shredders: These machines use blades to cut the wool fibers into smaller pieces. Blade shredders can be either single-shaft or double-shaft, with the latter offering higher throughput rates and better particle size control.

2. Hammer mills: Hammer mills use a series of rapidly rotating hammers to pulverize the wool fibers. This type of shredder is often used for coarser wool fibers or when a higher degree of fiber liberation is desired.

3. Rotary cutters: These machines use a cylindrical drum with cutting blades to shred the wool fibers. Rotary cutters are particularly effective for processing fine wool fibers.

4. Roller shredders: Roller shredders use a series of rollers with applied teeth to shred the wool fibers. This type of shredder is often used for high-volume applications and can handle a wide range of wool fiber types.

From this most common type of machine, blade shredders used in this study. Cutting is performed at the interface of the two opposing sets of blades. One is fixed and the other one is mounted on the rotor.

Figure 4. Before and after shredded wool

## 2.2 Shredder parts

Here are different shredder machine's components and their functions:

- **Shredding chamber**

This is the part of the shredder where the material is fed into the machine and processed. The shredding chamber may have different types of cutting mechanisms, such as rotating blades or hammers.

Figure 5. Shredding chamber

- **Hopper**

The hopper is the part of the shredder where the material is loaded into the machine. It can be set up in a different type of way, depending on the type of material being processed.

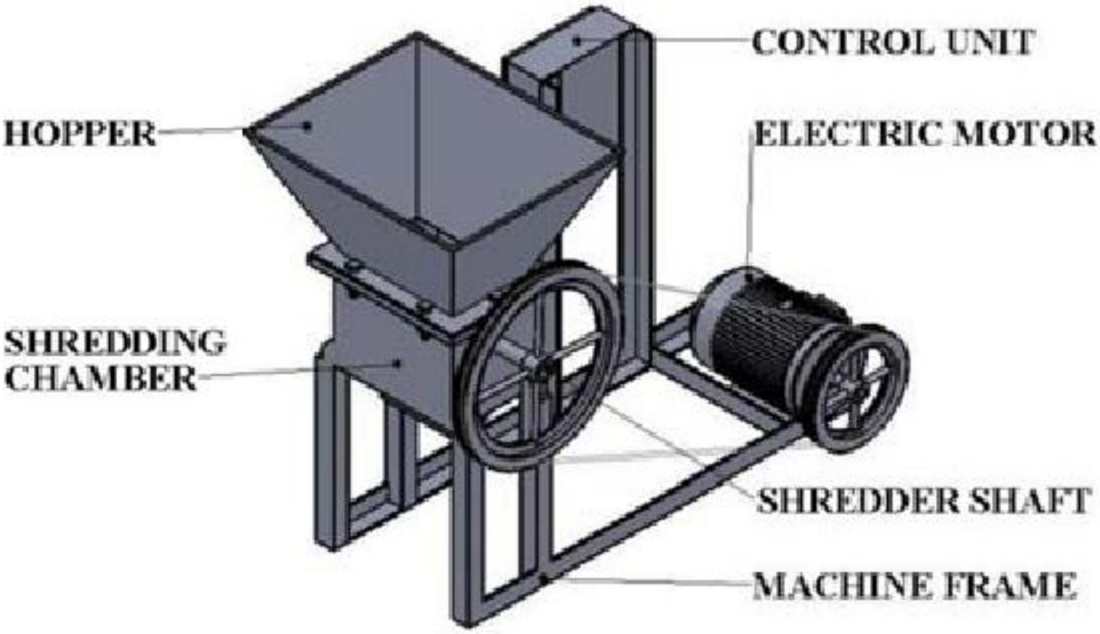


Figure 6. Hopper of shredding machine

- ## Screens

Screens are used to control the size of the shredded material. They are placed at the bottom of the shredding chamber and can be changed to adjust the size of the shredded material.

Figure 7. Screen of shredding machine

- ## Motor (electric)

The motor serves as the primary element responsible for imparting rotational motion to the rotor. It functions as an electrical machine, converting electrical energy into mechanical energy. In most cases, electric motors operate by utilizing the interplay between the motor's magnetic field and the electric current flowing through wire windings, resulting in the generation of torque that applies force to the motor's shaft.

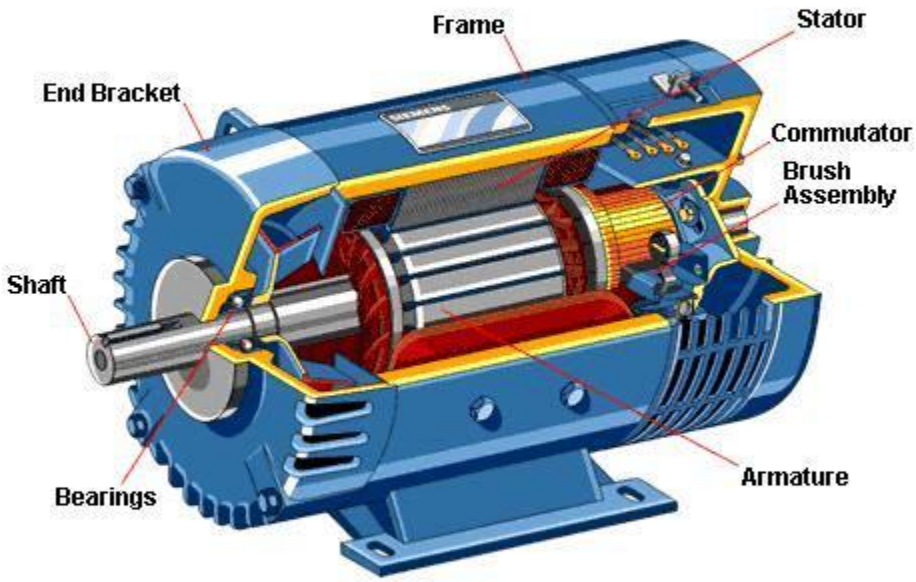


Figure 8. Motor components

The most common types of induction motors are 2 pole and 4 pole. For a 50 Hz supply, a 2-pole motor has a synchronous speed of 3000 RPM and a 4-pole motor has a synchronous speed of 1500 RPM (26). The frequency of the electrical supply (measured in Hertz, or Hz) is typically determined by the power grid of a country or region and remains constant under normal conditions. Most countries have a standard frequency of either 50 Hz or 60 Hz. For example, Europe, Australia, and most of Asia use 50 Hz, while North America and parts of Japan use 60 Hz (27). Electric motors can be powered by direct current (DC) sources, such as from batteries, or rectifiers, or by alternating current (AC) sources, such as a power grid, inverters or electrical generators which are bigger appliances (10).

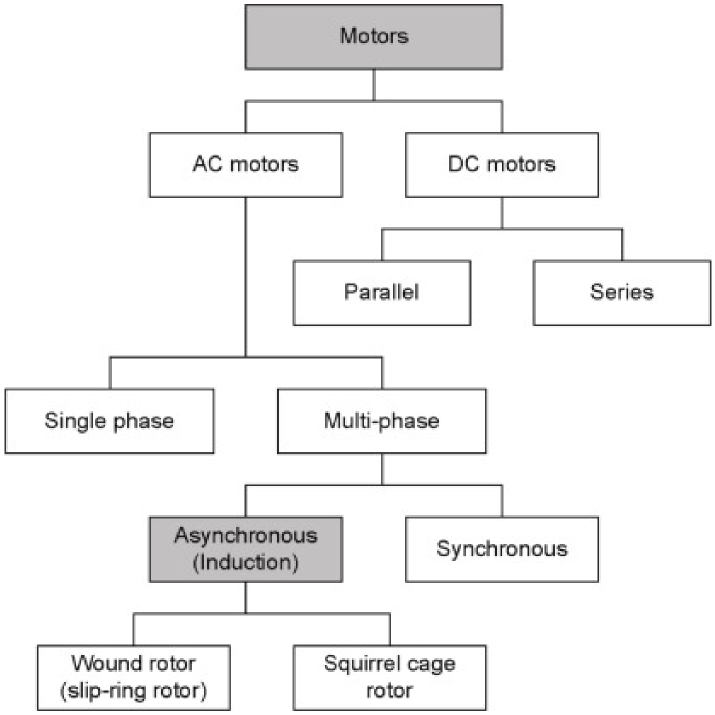

Figure 9. Motor classification

- **Rotor**

A rotor in a shredding machine is a rotating component with sharp blades or teeth that shred or cut materials such as paper, plastic, or metal into smaller pieces. The rotor is typically driven by a motor and rotates at a high speed, allowing it to efficiently shred materials as they are fed into the machine.

The rotor is typically a large, heavy-duty cylinder that rotates at a high speed within the shredding chamber.

The rotor is often built from a high-strength steel or alloy material that is resistant to wear and tear in order to ensure the durability and lifetime of the component. To further boost the rotor's strength and wear resistance, some hardening substance, like tungsten carbide or chromium, may be applied as a coating or treatment.

The rotor may be designed with a fixed or variable speed, depending on the requirements of the shredding process. A fixed speed rotor will operate at a constant speed, while a variable speed rotor can be adjusted to achieve different levels of cutting and shredding.

The rotor is typically supported by bearings, which are used to reduce friction and wear. Each type of rotor has its own unique design and is suited for different shredding applications, depending on the type of material being shredded and the desired output size. There are two basic types of rotor: single-shaft and multi-shaft. Multi-shaft shredder has two shafts, three shafts and four shafts.

### Single shaft shredder

It is best suited for larger, solid mass products such as tough materials, large parts, rolls of film and other difficult materials.

Typical applications:

- ❖ Baled film
- ❖ Large purgings
- ❖ Carpet bales
- ❖ Bowling balls
- ❖ Baled bottles


Figure 10. Single shaft shredders type

### Double shaft shredder

Compared to the single shaft shredder, the double-shaft metal shredder is a popular industrial shredder due to its low operating speed, high torque, and high throughput which can effectively treat a variety of materials.

Typical Applications:

- ❖ Tires
- ❖ Extruded sheet (not stacked)
- ❖ Gas Tanks
- ❖ Baled Film

- 55-gallon drums

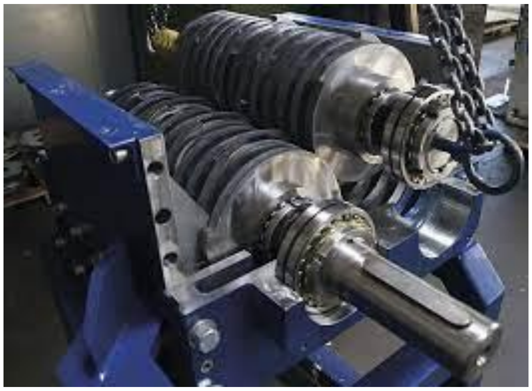

Figure 11. Double shaft shredder

### Triple shaft shredder

A three-shaft metal shredder has a cutting system featuring tough rotor blades with a sweeper shaft.

Figure 12. Triple shaft shredder

### Four shaft shredder

With 4-shaft shredders another set of rotors and cutting disks are added to the cutting chamber. They are designed to shred heavy duty materials at high volume. Operating at lower speed but higher torque, 4-shaft shredders are good for applications where small to medium particle size is desired.

Typical Applications:

- ❖ Polyethylene banding
- ❖ plastic film
- ❖ PET bottles
- ❖ Electronic scrap
- ❖ Tires
- ❖ Contaminated materials

Figure 13. Four shaft shredder

- ## Blades

The shredder blade is one of the most important parts of shredder. It is a kind of cutter that is equipped with an industrial shredder or granulator. The commonly used materials are 6CrW2Si, H13, skd-11, D2, DC53, LD, Cr12MoV, 9CrSi, etc. The quality of the shredder blade directly affects the service life and production efficiency of the shredder.

### Blade type materials

The shredder blade type chosen should reflect the materials being destroyed. Mostly blade material has high hardness material. Hardness ranges depending on the makeup of the blades. There are the most common types of shredder blades.

1. Carburizing Steel Shredder Blade

The carbon diffused into the surface of mild steel is used to increase the carbon content. After heat treatment, this produces harder steel with a wear-resistant layer.

2. Tool Steel Shredder Blade

Tool steels consist of carbide-forming elements. A tool steel shredder blade is a type of shredder blade made from tool steel, a high-carbon, high-chromium alloy steel that is known for its toughness, wear resistance, and ability to hold a sharp edge. Tool steel shredder blades are commonly used in industrial shredders that process materials such as metal, plastic, wood, and rubber. Tool steel shredder blades are designed to endure the stresses and strains of shredding tough materials. They are typically made from a variety of tool steel grades, such as D2, A2, M2, and S7, each of which has unique properties that make it suitable for different applications. For example, D2 tool steel is known for its high wear resistance and toughness, while A2 tool steel is prized for its ability to hold a sharp edge and resist deformation.

3. Case Hardened Shredder Blade

A case hardened shredder blade is a shredder blade that has undergone a process called case hardening. Case hardening is a heat treatment process that involves heating the metal to a high temperature and then rapidly cooling it in a hardening medium, such as oil or water. This process creates a hard outer layer, called the "case," while the inner core remains relatively soft and ductile.

The hard outer layer of the blade provides excellent wear resistance, while the softer inner core allows the blade to absorb shock and prevent cracking or chipping.

The case hardening process improves the performance and durability of shredder blades, making them more effective and longer-lasting.

Surface hardening steel results from the process of increasing the hardness of the outer surface of a metal. It is a very thin layer of metal that overlays softer metals to form a harder coating.

4. Chromium Low Alloy Steel Shredder Blade

Chromium low alloy steel shredder blades are high-quality cutting tools and typically made of steel containing a low percentage of chromium, which gives the blade excellent wear resistance, toughness, and durability. The addition of chromium to the steel increases its hardness, wear resistance, and corrosion resistance. These properties are important for shredder blades because they need to withstand the high stresses and impact forces of cutting and shredding. Chrome low alloy steel is creep resistant, which means it is designed to withstand high temperatures. It is useful because it has high strength and corrosion resistance properties. It can be found in many applications and industries.

5. Carbon steel blade

Carbon steels are a series of alloys of carbon and iron containing up to about 1% carbon and up to 1.65% Mn, with elements added in specific quantities and residual quantities of other elements. It is categorized into three main types depending on the amount of carbon present in the steel. There are low carbon steel (mild steel), medium carbon steel and high carbon steel. It's strong, versatile, and it can be used in a wide range of applications. (25)

## Blades shapes

There are different shapes of blades that are used in different applications. To name it:

1. Strip-cut blades

It has a series of parallel blades that are closely spaced to create long and thin strips of material. It is commonly used in offices or homes where there is a need to cut large volumes of papers. Also it has advantages which are faster and more efficient than cross-cut shredders.

2. Cross-cut blades

It is similar to the strip-cut blades which have two or more blades that intersect each other at an angle, creating small, confetti-like pieces of shredded material to cut the paper into small pieces.

Figure14. Cross-cut blades of shredder


Figure 15. Cutted paper strip-cut vs cross-cut

Those above two shredders are mostly used in paper shredding.

3. Piercing blades

The piercing action of the blades is pretty effective for shredding materials that are difficult to tear or shred, such as those with a high degree of resilience or thickness. These blades typically have a pointed tip that is designed to puncture and shred tough materials. It is used in shredding machines, designed for shredding materials such as corrugated cardboard or foam. Piercing blades are a powerful and effective tool for shredding tough, resilient materials in industry.

Figure 16. Piercing blade

4. Granulator blades

A granulator blade is a type of blade used to cut, shear and crush the plastic material, breaking it down into smaller pieces. It is made of high-quality steel and is designed to be durable and long-lasting. Granulator blades can be straight, curved or angled to help improve cutting and shredding performance. Below figure shows us a type of granulator blades.

Figure 17. Long granulator blade

Figure 18. Short granulator blade

Piercing blades can be used in conjunction with other types of blades, such as granulator blades, to achieve optimal shredding performance. The combination of piercing and granulator blades can help break down large pieces of material into smaller ones that can be more easily processed or disposed of.

5. Hook blades

Hook blades have a curved, hook-like shape that is designed to catch and tear the material being shredded and it is designed to cut the plastic, fabric or carpet. There are different types of hook. The size and curvature of hook blades can vary depending on the specific application and material being shredded.


Figure 19. Different types of hook

Also hook has another nomenclature which is edges.

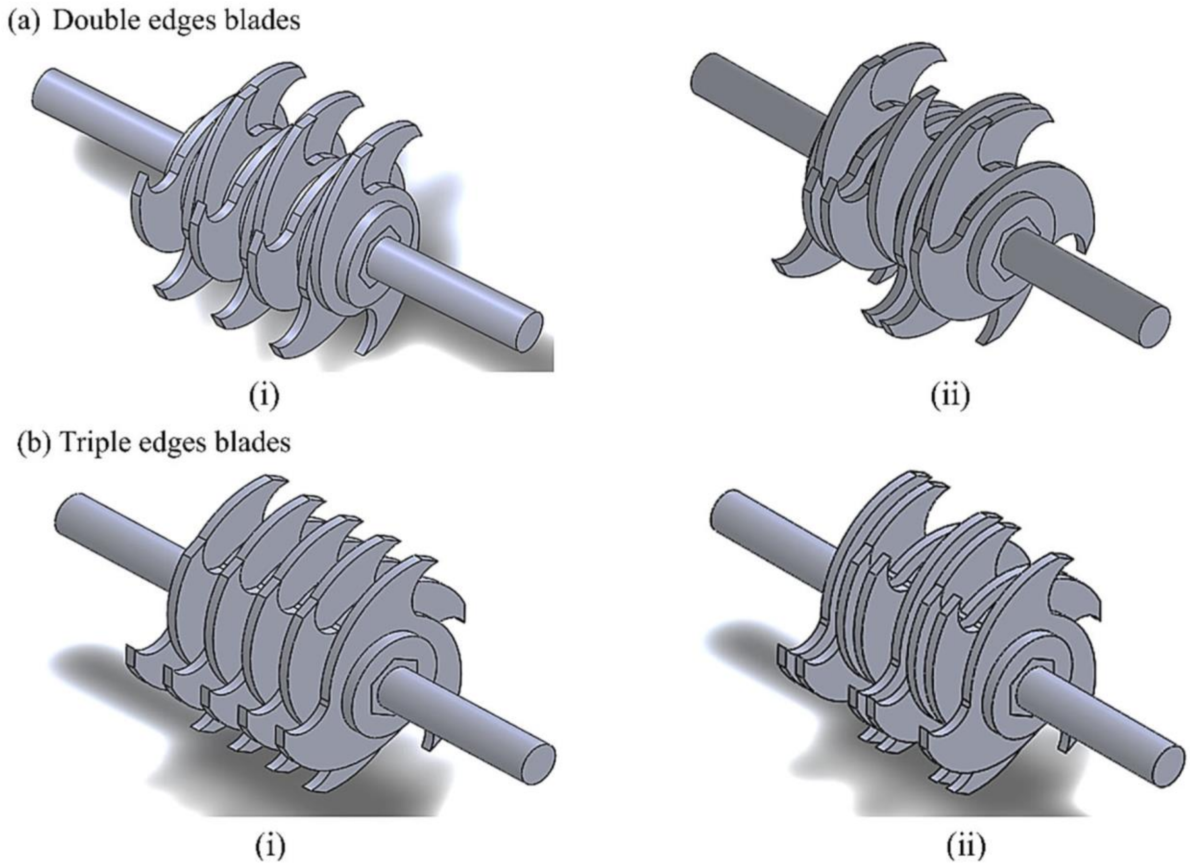


Figure 20. Double and triple edge blades

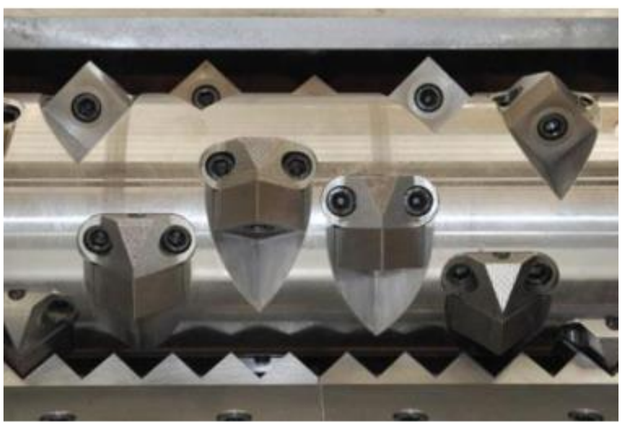

Figure 21. Blades on the rotor

This showed us a blade installation on the rotor.

This following figure shows the shredder blade knives that are placed on the rotor by nut and bolts.

Figure 22. Shredder blades knives

Figure 23. Shredder blades knives types

- **Bearings**

Bearing is an important component that is used to support the rotating components of the shredder to allow for smooth and efficient operation. The bearings must be able to withstand the high speeds and heavy loads that are generated during the shredding process. There are several types of bearing including ball bearing, roller bearing and sleeve bearing.
Ball bearings can handle both radial and axial loads. On the other hand, roller bearings are suited for high load applications and it can handle heavier loads than ball bearings.

Figure 24. Ball bearing

Figure 25. Roller bearing

Sleeve bearings are used in applications where the load is light and the speed is low.

Figure 26. Sleeve bearing

- **Drive System**

The drive system includes components such as belts, pulleys, and gears that transfer power from the motor to the cutting mechanism.

- **Control Panel**

The control panel is used to start and stop the shredder and may also have controls for adjusting the speed and other parameters of the shredder.

## 2.3 Factors affecting the efficiency of wool shredding machines

There are several factors that can affect the efficiency of the wool shredding process. Some of the most important factors include:

- Shredding machine type:

Different types of shredding machines use different mechanisms to shred the wool, such as cutting, tearing, or crushing depending on the application. The design of the shredding machine can affect its performance. For example, the size and shape of the shredding chamber and the motor power and speed can all impact the machine's shredding capability. One of the important components that are blades can affect the efficiency of the shredding process. There are rotor specifications, blade material, size, shape, thickness, angle of the blade and number of teeths.

Rotor affects:

A larger rotor diameter can generally handle larger pieces of material and can shred material more quickly than a smaller rotor. However, a larger rotor may require more power to operate, which can increase the cost of the shredder and the operating expenses.

Blade effects:
A larger blade angle can result in more efficient shredding, but it may also require more power and create more noise and vibration. A smaller blade angle may be less efficient but may require less power and produce less noise and vibration.

Blade angle - Blade angles between 15 to 25 degrees can be effective for wool shredding. A shallower angle, such as 15 degrees, can result in less force required for cutting and less wear on the blade, but may not provide as fine a shred as a steeper angle. A steeper angle, such as 25 degrees, can result in a finer shred but it may require more force and wear on the blade. (23)

Blade thickness - The thickness of the blades also can influence their durability and the fineness of the cut. Thicker blades are generally more durable and can handle tougher materials, however they may not cut as finely as thinner blades.

Blade material - The blades are usually made of high-quality tool steels like D2 or similar materials. The blades need to be hard enough to cut through the wool without dulling quickly, but not so brittle that they chip or break.

Number of teeths - The number of teeth can vary widely based on the machine design. More teeth can result in a finer cut, but it can also slow down the cutting process. Conversely, fewer teeth can speed up the cutting process, but the cut might not be as fine.

Size of the blade - Larger blades can handle more material at once, but they may also require more power to operate. On the other hand, smaller blades cannot be able to handle as much material at once, but they can often cut more precisely.

- Material properties:

The properties of the wool being shredded can affect the machine's performance.

For example, the density, fiber length of wool moisture content that is too much can cause the wool to mat or stick together, conversely too little moisture can make it brittle and difficult to shred.

These properties can impact how well it feeds into the machine, how effectively it is shredded. The type and quality of the wool can affect how it shreds. For instance, coarser wool may be more difficult to shred than finer wool, and matted wool may require more force to shred.

- Feed rate:

Feed rate of the wool into the shredding machine can particularly affect the shredding process. The feed rate that is too fast can cause the wool to become tangled or jam the shredding machine, on the other hand too slow of a feed rate can decrease efficiency. An experienced operator will know how to adjust the settings of the shredding machine and manage the feed rate to achieve the desired output.

The wool shredding process will depend on a variety of factors as mentioned before, and it is important to consider all of these factors when designing a shredding system or improving the shredding process.

## 2.4 Review of existing wool shredding machine

Our machine consists of several parts which have an electric motor, shaft, belt, shredding chamber, hopper, frame, screen, rotor, blade as well as bearing.

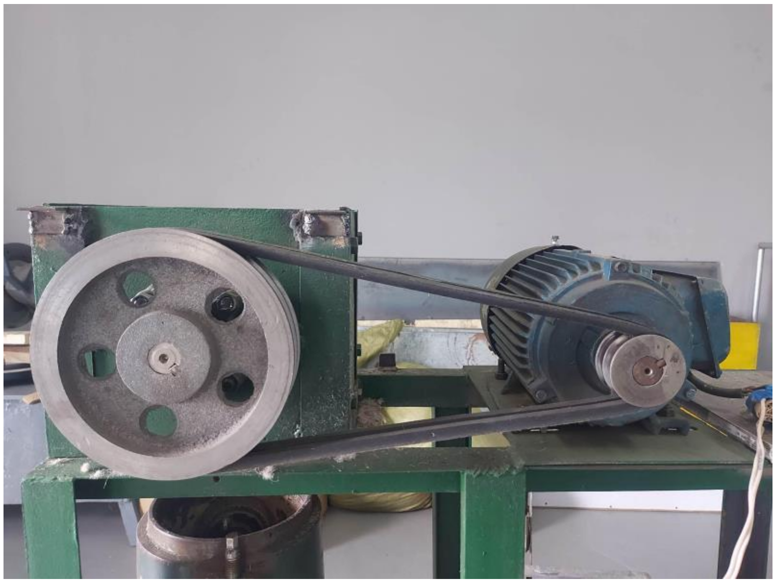

Figure 27. Front view of existing shredding machine

The drive mechanism of this machine is V-belt drive. A V-belt is a flexible and efficient power transmission device capable of transferring power from one shaft to another. (22) The shaft diameter connected with the motor is 67mm and the shaft diameter connected with the rotor is 220mm.


The following figure shows the technical specifications of a three phase asynchronous (induction) motor. There is a power rating of 3kW which translates to 4 horsepower, and a rotational speed of 2900 revolutions per minute.

Figure 28. Motor’s technical specifications

Figure 29. Blades in shredding chamber

The size of the shredding chamber used in this study was 26 cm by 28 cm, with a screen hole size of 2.5 cm. Also the blade was of the granulator type, with dimensions of 80 mm by 65 mm, and a spacing (acceptable gap) of 2 mm between blades. Cutting process conducted between fixed blade and shredder blades. There are a total of 12 blades, 3 series blades and each series has 4 blades.

The existing shredder machine under investigation in this study utilized a blade with a thickness of 10 mm. This blade was composed of high-speed steel (HSS), which is a subset of tool steels composed of over 40 alloyed tool steel variants containing carbon steel, alloyed with more than 7% tungsten or molybdenum.

Some properties of carbon steel:

- Density-7.85 g/cm3
- Young’s modulus [GPa] - 200
- Poisson’s ratio - 0.29
- Tensile strength [MPa] - 420

- ➢ Shear modulus [GPa] - 77.5194

Rotor diameter- 110mm, length of rotor- 2700mm

In a shredder machine, blades are mounted on the rotor, with spaces placed in between the blades. During the operation, material is shredded between fixed blades and blades which is mounted on the rotor.

# 3. Methodology

## 3.1 Testing

The several time experiment was conducted within a certain time. Based on the experiments, following results were obtained and shown on the evaluation table.

| Shredder | | | | | | |
|---|---|---|---|---|---|---|
| | Blade | Capacity of shredder | Noise | Safety | Power | Efficiency |
| Performance | Bad | Normal | Normal | Normal | Normal | Bad |
| Improvement | Needed | Needed | Normal | Normal | Normal | Needed |

Table 4. Evaluation table of shredder

In experiments, such factors were constant there including the feeding rate, wool material.

### 3.1.1 Calculation for the existing machine:

The calculation of rotor speed:

$$N1 * D1 = N2 * D2$$

Where, N1 - speed of driven pulley

D1 - diameter of driven pulley, 220mm

N2 - speed of drive pulley, 2900 revolution per minute of motor

D2 - diameter of drive pulley, 68 mm

$$N1 = N2 * D2/D1 = 68 * 2900/220 = 896.36\ rpm$$

Pulley ratio: $N2/N1 = 2900/896.36 = 3.23$

## Calculating the required force:

Cutting force (F) = Shear strength (τ) x Area of blade (A)

$$F = \tau * A, [N] \quad (6)$$

Shear strength (τ) is the maximum stress that the material being shredded can withstand before it shears. It is typically measured in pounds per square inch (psi) or Newtons per square meter ($N/m^2$)

Cross sectional area of material of cut is found by the shredder blade contacts.

Area of blade (A) = Length of blade (L) x Cutting edge (W)

$$A = L * W, [m^2]$$

$$A = 80 * 0.2 = 16\ [mm^2] = 0.000016\ [m^2]$$

$$S = 180 = 180\ M\ [Pa]$$

Shredding required force to cutting wool:

$$F = 180 * 10^6 * 0.000016 = 2880\ [N]$$

This value shows the maximum needed force to cut wool with those cutting edges. From the equation, when the area of cutting edge increased, the more force needed to cut the wool.

## Calculating the force given motor:

Motor power = 3kW which has an applied factor of safety. We assume the safety factor is 1.5 and consider the efficiency of the motor. A typical electric motor has efficiencies ranging from 75% to 95% and we consider the 90% efficiency of the electric motor we have.

Final required motor power = Required electrical power × Safety factor

Required electrical power = $3k/1.5 = 2k\ [W]$

Safety factor: Include a safety factor to apply for any unforeseen circumstances, such as increased load, wear and tear, or other factors that may affect the performance of the motor. This is usually around 1.1 to 1.5 times the calculated electrical power.

Required electrical power = Mechanical power / Motor efficiency
Mechanical power = $2k * 0.9 = 1.8k\ [W]$

Mechanical power (P) is the product of torque (T) and angular velocity (ω), where ω is the speed in radians per second.

$$P = T * w$$

$$w = rpm * 2\boldsymbol{\pi}/60 = 896.36 * 2\boldsymbol{\pi}/60 = 93.86\ [rad/s]$$

$$1.8k = T * 93.86$$

$$T = 1.8k/93.86 = 19.17\ [Nm]$$

which is the required the torque and it is determined by this equation:

$$T = F * r\ [Nm]$$

where F is the shredding force, r is the distance from axis of rotation to cutting point.
r - radius of the rotor which is 110 mm convert to 0.11 m

$$F = 19.17/0.11 = 174.3\ [N]$$

We have to increase this amount of force until it is equal to 2880 N.
From the calculation this force is dependent on the speed of the rotor and power of the electric motor. When the speed of the rotor which is driven is higher, we should have less force to shred. It is efficient for us.

In order to increase the required force, we have to decrease the speed of the rotor. Required force and speed of the rotor is inversely proportional to each other.

We did several experiments, collected the data and calculated the average of the data which is shown below.

Current performance of the shredding machine

| | 15 min | Per min | One blade per min | One blade per revolution |
|---|---|---|---|---|
| Shredded wool (kg) | 1.1 | 0.073 | 0.0061 | $6.8*10^{-6}$ |
| Shredded wool (g) | 1100 | 73.33 | 6.11 | 0.0068 |

Table 5. Average data of experiments

The current design comprises a total of 12 blades, with each blade responsible for cutting approximately 0.0068 grams of wool per revolution. This productivity level, however, is considerably low for efficient wool shredding operations.

The cutting edge of each blade spans an area of 0.00004 square meters, a parameter directly influencing the quantity of wool processed. Specifically, the 0.0068 grams of wool cut per revolution is contingent upon this particular cutting area.

## 3.2 Design and implementation of improvement

This section focuses on the design and implementation of improvement measures for the wool shredding machine, with the goal of increasing the effects of blade improving energy efficiency, and enhancing total operational effectiveness.

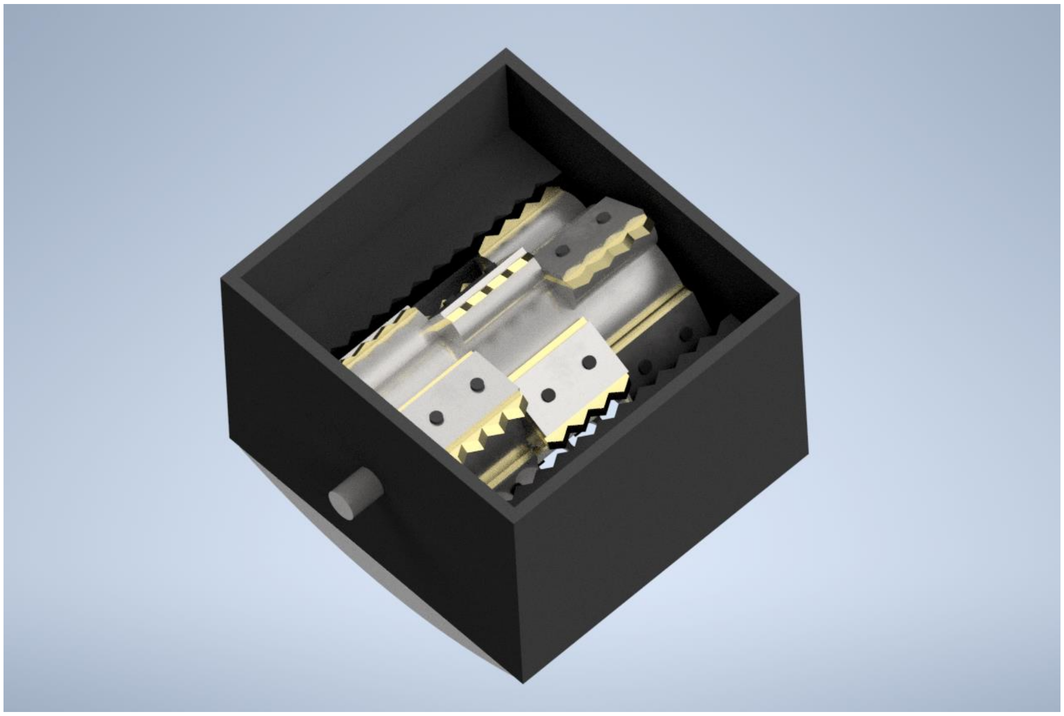
Figure 30. Shredding machine drawing

Shredding chamber size, diameter of the rotor, screen hole size was the same as before. To improve the efficiency of shredding wool, one changing component was shredder blade design.

### 3.2.1 Redesign of knives

This part is the one of the important parts for improving the productivity of shredding wool.

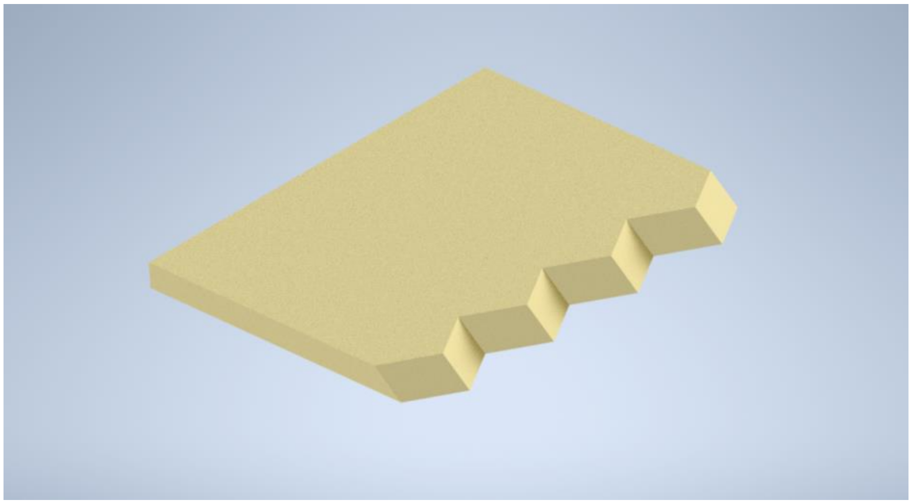
Figure 31. Shredder blade drawing with increasing amount of teeth

The dimensions of the blade are as follows: the length is 650 mm, the width is 80 mm, and the thickness is 5 mm. The slope length is 8 mm, this length is an important factor affecting the cutting action of the blade. The blade also has four teeth.

Then the blade angle will be $\boldsymbol{\alpha} = arcsin(5/7.7) = 40.5°$

When the number of teeths increases, the shredded wool will be finer. But it might slow down the process.

The design of the blade was changed and it leads to changing the cutting area.

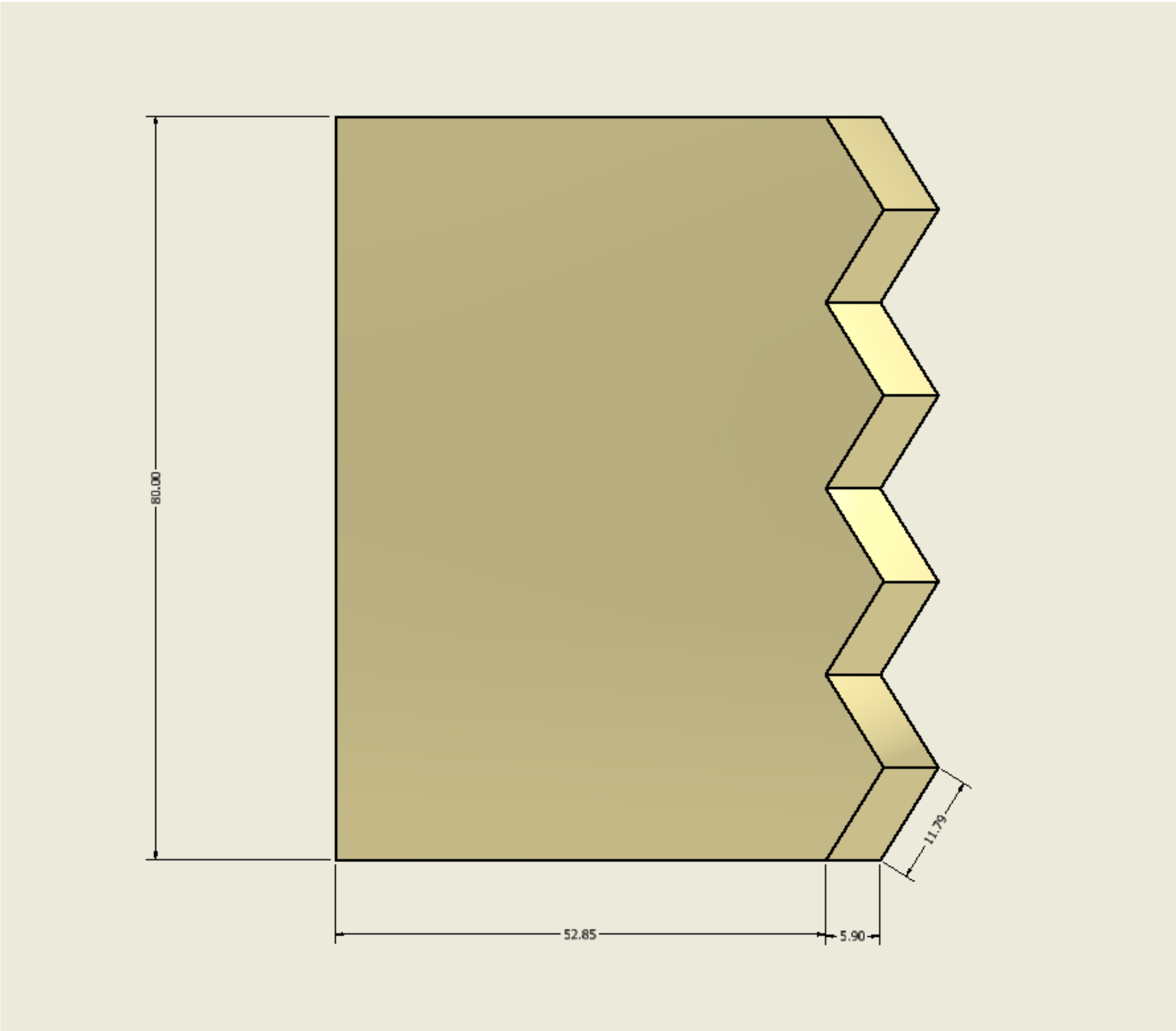


Figure 32. Front view of the shredder blade drawing with dimensions

Calculating the length of cutting edge:

$$5^2 + x^2 = 8^2$$

$$x = \sqrt{(8^2 - 5^2\ )} = 6.24\ [\square\square]$$

$$10^2 + 6.24^2 = y^2$$

$$y = \sqrt{(100 + 6.24^2)}\ = 11.79\ [\square\square]$$

$$L = 11.79 * 8 = 94.32\ [mm]$$

$$A = L * t = 94.32 * 0.2 = 18.864\ [mm^2] = 0.000018864\ [mm^2]$$

This area is almost the same as the current area of the blades.
From this we assume there is no sharp change in the cutting area.

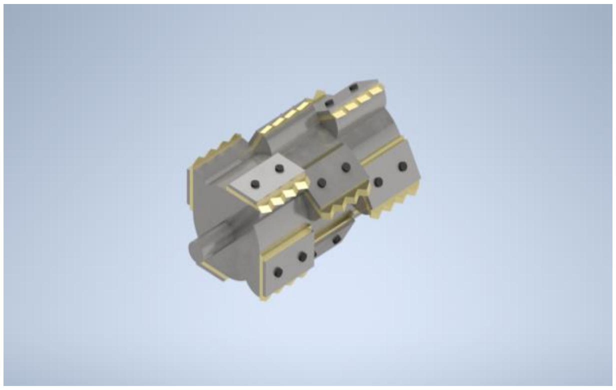

Figure 33. Rotor with blades drawing

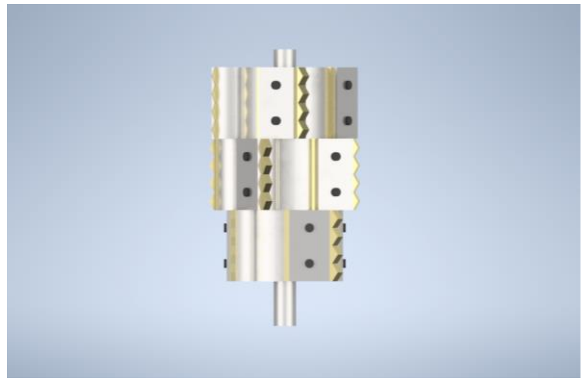

Figure 34. Top view of the rotor with blades

## 3.3 Calculation for improving the efficiency of shredding

Our demand is increasing the force from 147.3 to 2880 N to shred wool.

$$F = T/r = 2880\ [N]$$

The needed torque :

$$T = F * r = 2880 * 0.11 = 316.8\ [Nm]$$

Mechanical power: $P = T * w$

Current rpm of rotor : 896.36 rpm which is pretty fast, we need to reduce it a little bit.

To reduce the revolution per minute, we have to increase the diameter of the driven pulley.

Current diameter of the driven pulley is 220 mm, we assume that the increase to 500 mm.

$$N1 * D1 = N2 * D2$$

$$N1 = 2900 * 68/500 = 394.4\ (rpm)$$

where, 2900 rpm is the rpm of any 50Hz supplied motor which has any power.

The the angular velocity will be calculated following equation:

$$w = n * 2\boldsymbol{\pi}/60 = 394.4 * 2\boldsymbol{\pi}/60 = 41.3\ [rad/s]$$

and mechanical power will be : $P = T * w = 316.8 * 41.3 = 13084.3\ [W]$

Required electrical power = Mechanical power / motor efficiency

Consider the efficiency of the motor is 90%.

$$Pr = 13084.3/0.9 = 14538.1\ [W]$$

Final motor power = Required electrical power * safety factor

$$P = 14538.1 * 1.5 = 21807.1\ [W]$$

Here are the changes of motor power and diameter of the driven pulley.

This type of motor which has 21kW power, and diameter of driven pulley is 500 mm. These two big changes can shred any type of wool.

## 3.4 Stress analysis

Stress analysis is one of the most important steps in any structural design practice that determines how materials will respond under various types of loads. This is crucial in designing and evaluating under a stress investigation whether a given material or structure can withstand the forces. (28) Stress analysis can be divided into experimental or analytical method:

1. Experimental stress analysis approach involves testing a physical prototype or existing structure using various methods such as strain gauges, which measure the deformation or compression of the material when a force is applied.

2. Analytical stress analysis approach involves using calculations and simulations to predict how a structure or material will respond to a given force. The material's properties, such as its elasticity, shear strength, and tensile strength, are taken into account.

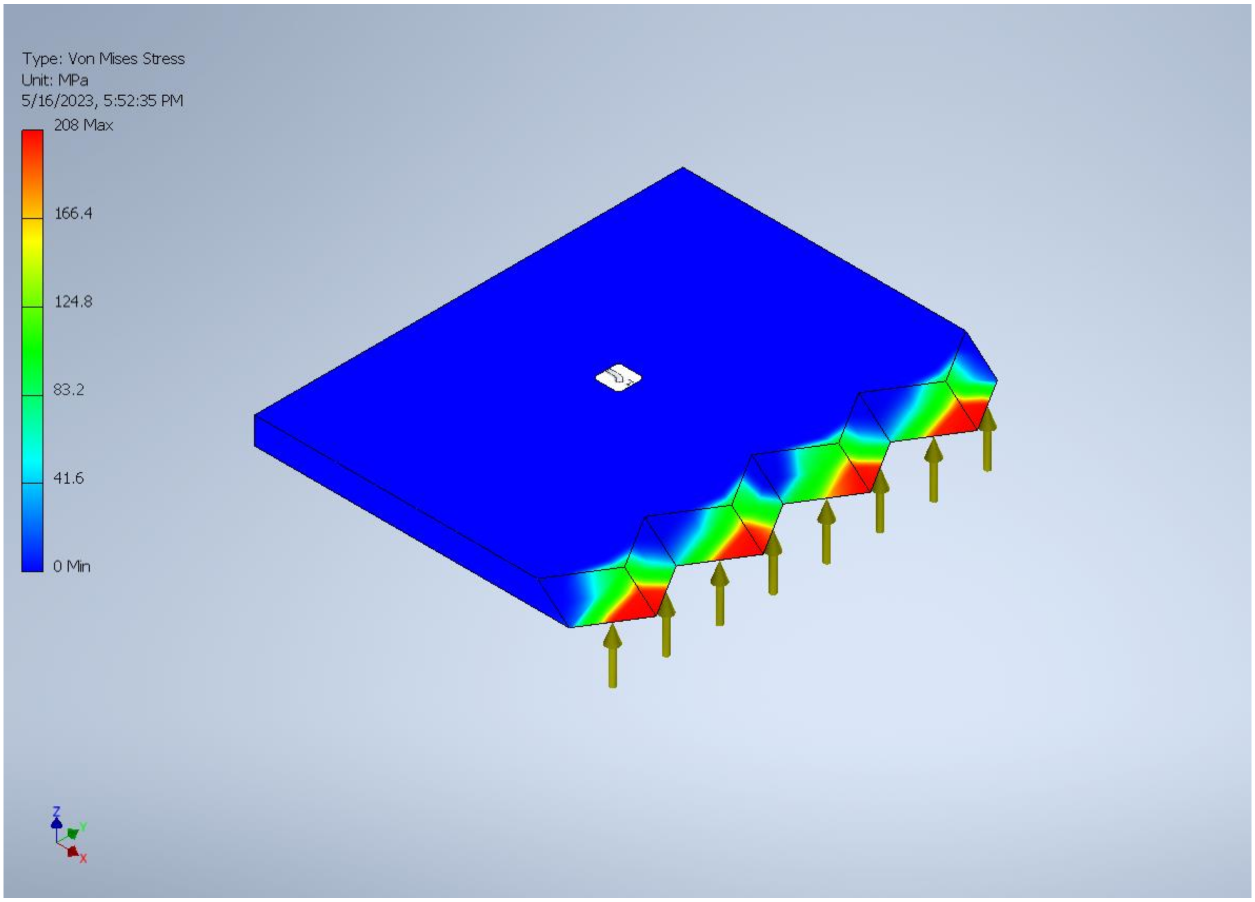

Figure 35. Stress analysis on the blade

In this study, we used the analytical type of stress analysis. This designed blade is analyzed with the help of Autodesk Inventor which is a computer aided design application. The above figure shows the stress acting section. The stress acts on the tip of the cutting edge at a small range.

## Material(s)

| | | |
|---|---|---|
| Name | Steel, Carbon | |
| General | Mass Density | 7.85 g/cm^3 |
| | Yield Strength | 350 MPa |
| | Ultimate Tensile Strength | 420 MPa |
| Stress | Young's Modulus | 200 GPa |
| | Poisson's Ratio | 0.29 ul |
| | Shear Modulus | 77.5194 GPa |
| Part Name(s) | ir.ipt | |

## Operating conditions

### Force:1

| | |
|---|---|
| Load Type | Force |
| Magnitude | 2880.000 N |
| Vector X | 0.000 N |
| Vector Y | 0.000 N |
| Vector Z | 2880.000 N |

Figure 36. Information about material and acting force

We used the carbon type of steel in an improved design same as the before.
Stress analysis is the most typical application of FEM which is used to predict the response of materials to heat, vibration, and other physical effects. Stress analysis must be accurately performed, as it significantly contributes to the safety and efficiency of structures and materials. Incorrect predictions can lead to structural damage, material failure or even catastrophic accidents.

# 4. Results and discussion

## 4.1 Results

In this study, we have derived several significant findings. Our selection of materials and design decisions were informed by these results.

We chose a carbon steel variant due to its inherent properties that has good hardness and aligns with our project requirements. Additionally, we decided to utilize a blade with a reduced angle to improve the efficiency of the cutting process for reasons that are less power required for cutting and less wear on the blade.

Findings were also made in the operational parameters of the shredding machine. To reduce the rotor speed, we proposed an increase in the diameter of the driven pulley from the initial 220 mm to 500mm. It was critical to balance the pulley's size, as an excessively large diameter would compromise the overall design of the shredder machine.Thus, we concluded that a diameter of 500mm for the driven pulley strikes the appropriate balance in this design.

Our statistical analyses suggested that a motor power of 21kW would be necessary for optimal shredding of wool. However, the practicality of such a high-powered motor in the real-world application of a wool shredding machine is impossible. Another important finding was the redesign of knives. Redesign of knives leads to increasing the area of cutting edge, it means the increasing the amount of shredded wool per revolution.

We discovered another finding that the fundamental frequency of a shredder equipped with four blades was very efficient. This higher frequency recommends that a four-blade shredder own great stiffness when compared to its counterparts with different blade configurations.

Consequently, we selected a shredder design that incorporates four blades to take advantage of this increased stiffness and improved performance.

## 4.2 Limitations and future developments

Throughout the course of this study, we have desired some limitations for improving the efficiency of wool shredding. For example: there is no change in the general size of the frame that has rotor diameter, bearing, shredding chamber size. We did calculations in the existing machine with some changes.

According to this study, there is a possible development for another improvement for wool shredding machines. It was found that using double shaft shredding machines instead of single shaft shredding machines. Also there is possibility to redesign such as use the more powerful motor and increase the shredding capacity.

Following figure shows the shredding wool process with a double shaft shredder.

Figure 37. Double shaft wool shredder

# 5. Conclusion

In conclusion, this study has provided a comprehensive examination of the existing wool shredding machine and proposed several modifications aimed at improving its total performance and efficiency. Although limited by certain constraints such as the size of the frame, rotor diameter, bearing, and shredding chamber size, the study has non identified several approaches for improvement within these confines.

The research findings suggest that one of the significant improvements could be achieved by transitioning from a single shaft shredding machine to a double shaft shredding machine. The double shaft design was found to offer potential benefits for enhanced shredding performance and increased processing capacity.

Additionally, the study has proposed a comprehensive redesign of the machine to further improve its performance. This includes the more powerful motor, which could influence the shredding power and increase the machine's processing capacity.

While the current study provides a solid foundation for the enhancement of the wool shredding machine. Future studies could put into the specific design aspects of the double shaft shredder, the environmental impact of these machines to further optimize the wool shredding process.

The results of this study are expected to contribute to the development of a more efficient and cost-effective wool shredding machine, which will benefit the textile industry and the environment. The proposed solutions could also be applied to other types of shredding machines, thereby extending the scope and impact of the research.

In summary, I believe that the findings of this research contribute valuable insights to the body of knowledge on wool shredding machines and think ahead for future innovations in this field.

# 6. Reference


1. Wikimedia Foundation. (2023, May 16). Wool. Wikipedia. https://en.wikipedia.org/wiki/Wool
2. Wool, Wool's uses and benefits. Econation. (2020, December 19). https://econation.one/wool/
3. Why wool?. WILD VALLEY FARMS. (n.d.). https://www.wildvalleyfarms.com/why-wool.html
4. I.M.Sanjay Kumar, DR. T.R. Hemanth Kumar, Design and Development Of Agricultural Waste Shredder Machine. 2015 Oct;2(10):169
5. Tran Thanh Tung, Luong Thi Hong Ngoc, Nguyen Xuan Quynh, Tran Vu Minh. DESIGN AND ANALYSIS OF A PAPER SHREDDER MACHINE. 2021 [cited 2023 May 16] Sep;7(3) https://actatecnologia.eu/issues/2021/III_2021_04_Tung_Ngoc_Quynh_Minh.pdf
6. Prof. M. S. Motghare, T. U. Mule, M. S. Chafle, S. D. Tandulkar, S. K. Damahe, S. M. Tembhurkar. Design and Development of Shredder Machine for Plastic Waste Recycling. 2021 Jun;6(2) https://ijarsct.co.in/Paper1547.pdf
7. LLC, M. (n.d.). Mongolia is a first ever organic wool fertilizer exporter of the world. monpellets.com. https://monpellets.com/en/content/32
8. Two Shaft Shredder. (n.d.). https://www.joyalcrusher.com/products/shredder/two-shaft-shredder.html?gclid=CjwKCAjwl6OiBhA2EiwAuUwWZWFhsTXqxlWHdWwBdrWInPhqTRgt467vlBhtZPt9BkBaECZM9CDe5xoC5AkQAvD_BwE
9. Patwary, Engr. M. Z., Ansar, Vashni, the_quaxterr, Shakil, Yadav, S., Jeff, Sharma, S., Huxley, Hasanuzzaman, Holdsworth, P., Hazeena, A., No, & Steve. (2022, June 8). Physical and chemical properties of wool fiber: Textile Fashion Study. Textile and Fashion Design Study Blog. https://textilefashionstudy.com/physical-and-chemical-properties-of-wool/#:~:text=Tensile%20Strength%3A%20The%20tensile%20strength,%E2%80%93%2050%25%20in%20wet%20conditions.&text=Specific%20Gravity%3A%20Specific%20gravity%20is,regain%20is%2016%20%E2%80%93%2018%25
10. Wikimedia Foundation. (2023a, May 12). Electric motor. Wikipedia. https://en.wikipedia.org/wiki/Electric_motor

11. Rasmus Ekman. Development of a Plastic Shredder. Lund, Sweden: Department of Design Sciences Faculty of Engineering LTH, Lund University; 2018. [cited 2023 May 16] https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=8938831&fileOId=8938833
12. Doyle, E. K., Preston, J. W. V., McGregor, B. A., & Hynd, P. I. (2021, May 17). Science behind the wool industry. the importance and value of wool production from sheep. OUP Academic. https://academic.oup.com/af/article/11/2/15/6276818
13. Calculations required for shredder. Dave Hakkens. (2018, May 4). https://davehakkens.nl/community/forums/topic/calculations-required-for-shredder/index.html
14. Mahadev, B Mohammed Adil, Abhishek Y K, Manish Kumar, Amith Acharya. Design and Fabrication of Agricultural Waste Shredder Machine. 2020 [cited 2023 May 16];3(1) file:///C:/Users/a/Downloads/Design%20and%20Fabrication%20of%20Agricultural%20Waste%20Shredder%20Machine%20-HBRP%20Publiction%20(1)1%20(1).pdf
15. J H Wong, M J H Gan, B L Chua, M Gakim, N J Siambun. Shredder machine for plastic recycling: A review paper. 2022 [cited 2023 May 16] 1217 https://iopscience.iop.org/article/10.1088/1757-899X/1217/1/012007/pdf#:~:text=Nevertheless%2C%20the%20cutting%20angle%20ranging,16%2C%2025%2D27%5D
16. Truents. (2022, January 27). Wool fiber - basics, characteristics, & properties. Textile School. https://www.textileschool.com/162/wool-fiber-basics-characteristics-properties/
17. Durrani, A. (2016, February 28). Force required for cutting process. Physics Forums | Science Articles, Homework Help, Discussion. https://www.physicsforums.com/threads/force-required-for-cutting-process.859158/
18. Daria Jóźwiak-Niedźwiedzka, Alessandro P. Fantilli. Wool-Reinforced Cement Based Composites. 2020 Aug [cited 2023 May 16]; 13(16) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7475810/#:~:text=Wool%20is%20characterized%20by%20a,GPa%20%5B16%2C17%5D
19. Neha Joshi, Prof. Dhiresh Desale. DESIGN OF A PLASTIC / RUBBER SHREDDER MACHINE FOR RECYCLING AND MANAGEMENT OF WASTE. 2021 [cited 2023 May 16]: 7(4)

https://ijariie.com/AdminUploadPdf/Design_of_a_plastic___rubber_shredder_machine_for_recycling_and_management_of_waste_ijariie15033.pdf

20. Margot Chevalier. The potential of Mechanical recycling of post consumer textiles. Amsterdam, The Netherlands, Lille, France:Saxion University of Applied Sciences; 2021 April. [cited 2023 May 16]. https://www.dotheretex.eu/assets/uploads/site/The-potential-of-mechanical-recycling-for-post-consumer-textiles.pdf
21. 697: Tensile vs. shear strength. 697: Tensile vs. Shear Strength - explain xkcd. (n.d.). https://www.explainxkcd.com/wiki/index.php/697:_Tensile_vs._Shear_Strength#:~:text=Tensile%20strength%20represents%20how%20hard,cut%20it%20without%20it%20breaking.
22. Industrial Quick Search. (n.d.). Industrial Quick Search. V-Belt: What Is It? How Does It Work? Types Of, Uses. https://www.iqsdirectory.com/articles/conveyor-belts/v-belt.html#:~:text=V%2Dbelts%20are%20used%20because,reducing%20slip%20and%20power%20loss.
23. Detailed discussion on knife sharpening angles. SharpeningSupplies.com. (n.d.). https://www.sharpeningsupplies.com/Detailed-Discussion-on-Knife-Sharpening-Angles-W28.aspx
24. Robert L. Norton. Machine-Design: 2006 [cited 2023 May 16]. file:///C:/Users/a/Downloads/324768772-Machine-Design-Robert-L-Norton-pdf.pdf
25. Carbon Steel. Carbon Steel - an overview | ScienceDirect Topics. (n.d.). https://www.sciencedirect.com/topics/chemistry/carbon-steel#:~:text=Carbon%20steels%20are%20a%20series,residual%20quantities%20of%20other%20elements.
26. Tobias, M. (2023, April 4). What determines the rotating speed of a motor?. MEP Engineering & Design Consulting Firm. https://www.ny-engineers.com/blog/what-determines-the-rotating-speed-of-a-motor#:~:text=For%2050%20Hz%20motors%2C%20the,1%2C500%20rpm%20with%204%20poles.
27. Frequency – what it is, and why it’s important. (n.d.). https://www.djtelectricaltraining.co.uk/downloads/50Hz-Frequency.pdf
28. Stress analysis. Stress Analysis - an overview | ScienceDirect Topics. (n.d.). https://www.sciencedirect.com/topics/materials-science/stress-analysis