MARMARA UNIVERSITY
FACULTY OF ENGINEERING

THE EFFECT OF PROCESS PARAMETERS ON THE ROTARY TUMBLER

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GRADUATION PROJECT REPORT
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By

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June, 2025

ERHAN BARTU CORT

İBRAHİM ENGİN KURTOĞLU

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ABSTRACT

The Effect Of Process Parameters On The Rotary Tumbler

The research analyzed how different process variables affect the performance of a rotary tumbler. A custom rotary tumbler underwent fabrication to study how operational conditions affect surface finishing. The research used walnut shells as environmentally friendly abrasive media because they provide effective polishing while metal coins functioned as standard test specimens.

Theoretical simulations and approximations were used to analyze the effects of rotational speed and tumbling duration and media-to-material ratios. The rotary tumbler operated through a DC motor (RS775, 12V, 12000 RPM) which received power from an adjustable power supply and a PWM speed controller. The belt-driven system used timing pulleys to transmit rotational motion to the shaft.

The results showed that surface quality and process efficiency depend heavily on rotational speed because specific conditions were found to produce the best surface smoothness while minimizing material loss. The results showed that surface finishing improved with longer tumbling time until a specific point where efficiency started to decrease.

The research findings offer essential guidelines to optimize rotary tumbling operations by demonstrating how operational parameter control leads to specific metallic material surface characteristics.

SYMBOLS

RPM_{shaft} : Rotational speed of the shaft

RPM_{motor}: Rotational speed of the motor

T_{motor} : Torque generated by the motor

T_{shaft} : Torque transmitted through the shaft

η : Efficiency of the power transmission system

r_{shaft} : Radius of the driving shaft

$r_{tumbler}$: Radius of the tumbler drum

N_c : Critical speed of the shaft

g : Acceleration due to gravity

R : Inner radius of tumbler

Fr : Froude Number

w : Angular velocity

m : Mass of the object inside the tumbler

F_c : Centrifugal force

F_g : Gravitational force

F_{total} : Total resultant force

M : Maximum bending moment

S : Section modulus of the shaft

SF : Safety Factor

L : Length of the shaft

σ : Bending Stres

δ : Shaft deflection

I : Moment of inertia of the shaft cross-section

$N_{critical}$: Critical speed of the shaft

F_D : Resultant dynamic load acting on the bearing

C_{10} : Basic dynamic load rating

a_f : Application factor

L_D : Equivalent dynamic bearing load

x_D : Bearing life in millions of revolutions

x_0 : Weibull location parameter

θ : Weibull scale parameter

b : Weibull shape parameter

a : Life exponent

R_D : Reliability

$C_{10,required}$: Minimum required basic dynamic load rating of the bearing

ABBREVIATIONS

A : Ampere

DC : Direct Current

GT2 : Gates Tooth 2 mm pitch (timing belt standard)

MDF : Medium Density Fiberboard

PWM : Pulse Width Modulation

RPM : Revolutions Per Minute

V : Volt

1. INTRODUCTION

The manufacturing industry depends on surface finishing processes to improve metal component surface quality and extend their durability and functionality. The surface finishing technique rotary tumbling has become widely used because it provides simple operation at low cost while delivering uniform treatment to irregularly shaped objects. The surface finishing process of rotary tumbling operates by rotating a container with abrasive media and workpieces which leads to continuous surface abrasion and polishing and smoothing effects.

A customized rotary tumbler system was created to analyze how rotational speed together with tumbling duration and media-to-material ratio affect surface finishing results. The researchers chose walnut shells as abrasive media because they are environmentally friendly and biodegradable and show excellent polishing results on soft metals. Standardized test specimens used in this study consisted of metal coins to evaluate the results.

A DC motor (RS775, 12V, 12000 RPM) operated the rotary tumbler system through an adjustable power supply and PWM speed control unit. The motor rotational motion reached the main shaft through a timing pulley system which connected a 30 tooth pulley to the motor shaft with an 80 tooth pulley attached to the driven shaft via a GT2 timing belt. A separate shaft within the system maintained balanced rotation but operated independently from the motor.

The experiments were simulated through theoretical calculations which used realistic operational conditions and literature-based information because practical measurements were not performed.

The main goal of this research involves optimizing rotary tumbling parameters to achieve better surface finishing quality while reducing material waste and improving total process efficiency.

1.1. Literature Review

Rotary tumbling has been widely utilized as a surface finishing process in various industries, including automotive, aerospace, manufacturing, and jewelry. It has been primarily used for polishing, deburring, and cleaning workpieces by inducing controlled friction and impact between the parts and abrasive media. Numerous studies have demonstrated that the effectiveness of tumbling operations is largely dependent on parameters such as drum rotation speed, media type, and the material properties of the workpieces.

1.2. Historical Background of Tumbling Technology

The earliest methods of surface smoothing through mechanical motion with abrasives led to the development of tumbling techniques. The first mechanical tumblers emerged during the early 1900s to polish ammunition casings together with small metal components. Mass production industries including automotive and aerospace sectors adopted tumbling systems as standard practice during the middle part of the 20th century. The process evolved through time because of technological progress in materials science and motor control systems and automation systems which made it more efficient and precise and customizable.

1.3. Types of Tumbling Systems

Tumbling machines are generally categorized into two main types: rotary tumblers and vibratory tumblers

1.3.1. Rotary Tumblers

- The operation of Rotary Tumblers depends on rotating a drum which holds parts together with media. The rotating motion of the drum makes the contents collide with each other which produces surface interactions through impact and abrasion. The gentle tumbling action of rotary systems makes them suitable for processing small or delicate components with irregular shapes.

Figure 1.1 Rotary Tumbler

Figure 1.2 Rotary Tumbler

1.3.2. Vibratory Tumblers

Figure 1.3 Vibratory Tumbler

- The operation of Vibratory Tumblers depends on high-frequency vibrations which quickly agitate the contents to achieve faster processing and better surface finish control. These systems typically cost more and need advanced construction methods.

Figure 1.4 Vibratory Tumbler

1.3.3. Magnetic Tumblers

- Magnetic Tumblers use magnetically driven stainless steel pins or media, especially useful for cleaning and finishing intricate or small metal parts where conventional methods struggle.

Figure 1.5 Magnetic Tumbler

Figure 1.6 Magnetic Tumbler

1.3.4. Centrifugal Tumblers

- Centrifugal Tumblers employ centrifugal force, significantly accelerating the polishing process. Centrifugal tumblers are suitable for precision polishing tasks that require rapid finishing with tight dimensional tolerances.

Figure 1.7 Centrifugal Tumbler

Figure 1.8 Centrifugal Tumbler

The development of centrifugal and magnetic tumblers has led to the creation of advanced systems which need higher energy input and precise processing conditions.

1.4. Structure and Working Principle of Rotary Tumblers

A standard rotary tumbler includes a rotating drum together with its drive mechanism (motor, pulleys, belt) and support shafts and internal media. The horizontal drum rotation creates a grinding and polishing effect through the repeated motion and contact of contents that rise and fall inside the drum.

The process effectiveness depends on four main factors which include rotational speed and drum size and angle of inclination and media shape and material and cycle duration. The surface quality and material removal rate show substantial changes when parameters are adjusted slightly.

1.5. Tumbling Media and Material Properties

The selection of abrasive media for tumbling operations depends on workpiece characteristics and desired finish results because different materials and shapes exist. The primary types of media consist of:

- Ceramic Media: The material provides strong cutting power and long-lasting durability which makes it suitable for rough deburring and surface finishing operations.
- Plastic Media: The material works with a soft touch which makes it suitable for finishing both soft metals and plastic components.
- Steel Media: The material serves for intense burnishing operations as well as powerful polishing applications.
- Organic Media : Used in dry polishing applications for delicate parts.

The selection of media geometry between cones, cylinders, pyramids and spheres becomes crucial for processing components with complex shapes and internal spaces.

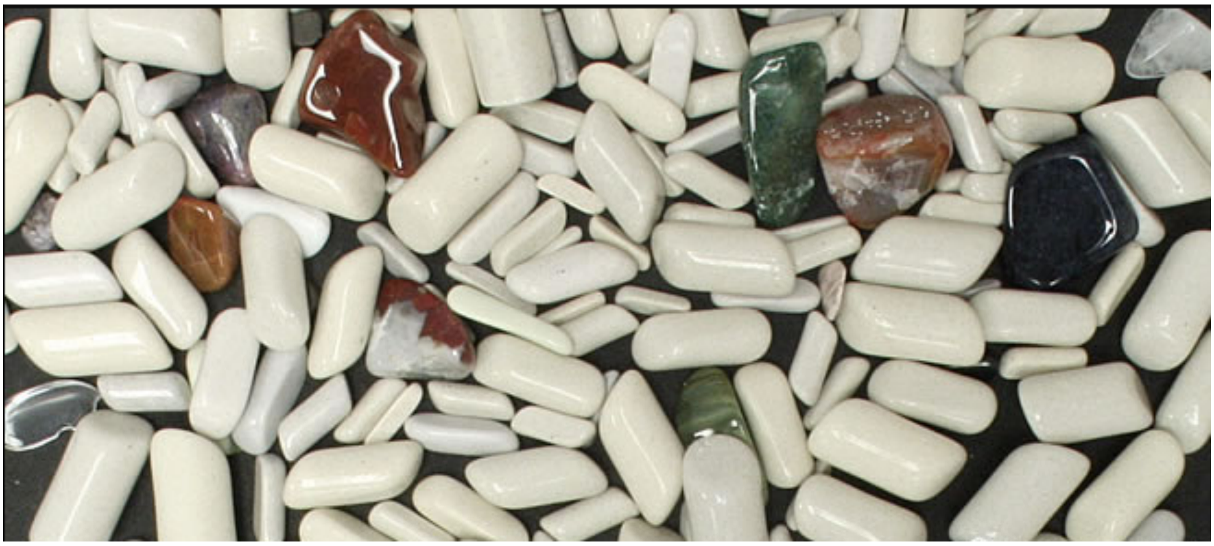

Figure 1.9 Ceramic Media

Figure 1.10 Plastic Media

Figure 1.11 Steel Media

Figure 1.12 Organic Media

1.6. Industrial and Research Applications

Rotary tumblers operate in numerous sectors across different industries.

- Automotive industry: For the deburring of pins, gears, and fasteners.
- Aerospace industry: For edge rounding of turbine blades and aluminum parts.
- Jewelry: For polishing rings, chains, and decorative components.
- Firearms industry: For cleaning spent brass casings.
- Electronics and manufacturing: For smoothing and preparing metal and plastic housings.

Academic and research laboratories use small-scale rotary tumblers to conduct studies about wear resistance and surface behavior and processing variable effects in controlled environments.

1.7. Literature Gaps and Study Motivation

The scientific community has extensively studied tumbling technologies but few researchers have focused on creating affordable adjustable educational rotary tumbler systems. Most commercial systems function best for particular industrial applications yet they do not offer modular design or user-friendly configuration options. The literature shows an unmet need for compact flexible prototypes which enable users to study process parameter effects in laboratory settings.

The research developed a rotary tumbler system to analyze how speed variations together with media selection and material choices affect tumbling process performance and efficiency. The system uses standard components which makes it possible for academic institutions to reproduce and access the system

2. DESIGN OF BALL MILLING SYSTEM

In this section, the conceptual and structural design of the rotary tumbler system, functioning similarly to a ball milling device, is presented. The system was designed to enable controlled abrasive testing on metallic components using rotational motion and ceramic media. Key considerations included selecting a suitable motor, determining appropriate speed ranges, and designing a durable and enclosed chamber for safe operation. The overall setup aimed to simulate industrial-scale tumbling processes on a laboratory scale, while allowing for flexibility in speed adjustment and ease of sample replacement.

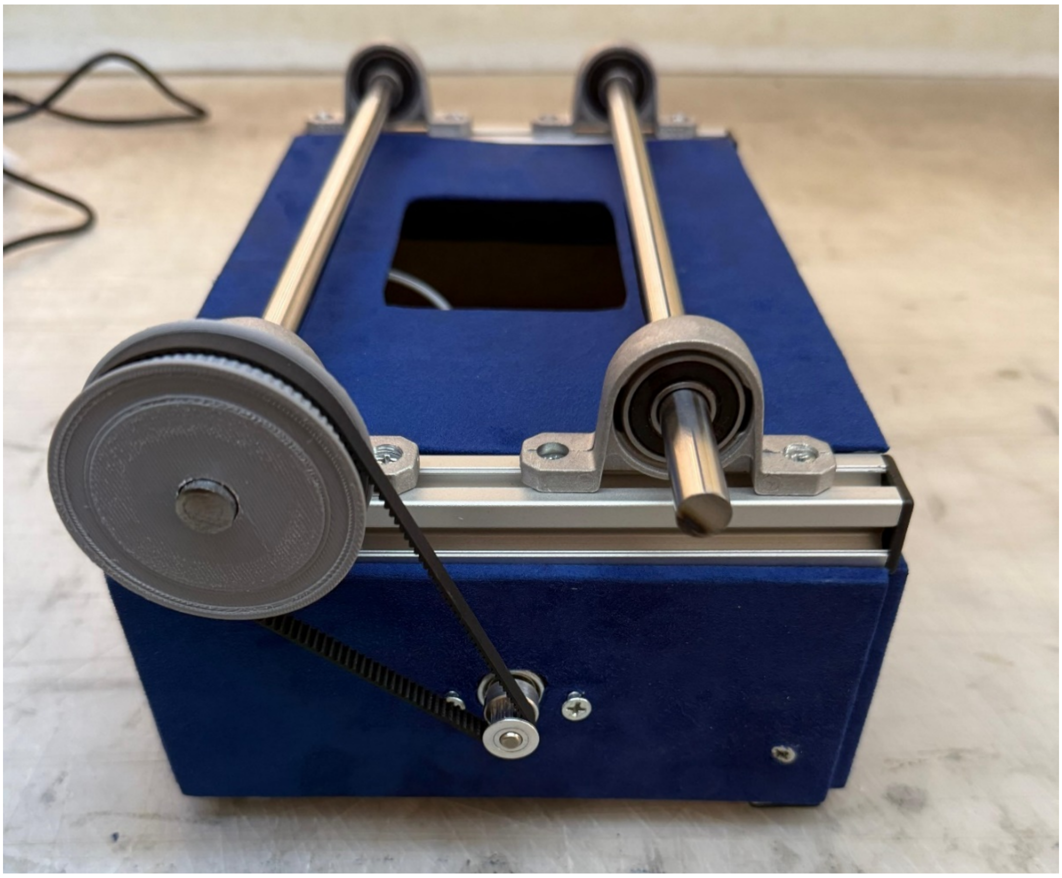

Figure 2.13 Final Product

2.1. COMPONENT SELECTION

2.1.1. DC Motor Comparison

Motor Model	Voltage (V)	RPM	Power (W)	Advantages	Disadvantages
RS775 DC Motor	12	12000	~150	High RPM, compact, easily available, economical	Overheating at prolonged use, requires speed regulation
RS550 DC Motor	12	10000	~100	Lower power consumption, moderate RPM	Lower torque, limited power
Stepper Motor (NEMA17)	12–24	200–600	~40–60	Precise speed control, stable low RPM	Limited high speed capability, lower power

Table 2.1. DC Motor Comparison

Evaluation:

Why RS775 DC Were Selected

The RS775 DC motor was chosen because it has high RPM and sufficient torque to perform tumbling operations at various rotational speeds. The availability, affordability, and compact size of the motor were also important factors in this decision. Although overheating concerns exist, these can be effectively managed by proper speed control mechanisms.

Figure 2.14 RS775 DC Motor

2.1.2. Power Supply Comparison

Power Supply Type	Voltage Range (V)	Current Rating (A)	Advantages	Disadvantages
Adjustable Adapter	3–12	10	Flexible voltage adjustment, high current, good stability	Potential heat generation at high loads
Fixed DC Power Supply	12	5	Stable output, simplicity, lower cost	Limited flexibility in voltage adjustment
Laboratory Bench Supply	0–30	5–10	Precise and stable control, versatile	Higher cost, less portability

Table 2.1 Power Supply Comparison

Evaluation:

The adjustable adapter (3-12 V, 10 A) proved useful for testing different operating conditions and speeds. The adapter provided precise control of motor speed and operational parameters which proved essential for determining the optimal tumbling conditions.

Figure 2.15 Pm-22380 12 Volt - 10 Ampere Voltage Step Adapter With 5.5 2.5Mm Tip

2.1.3. Pulley System Comparison

Pulley Configuration	Teeth Ratio	Advantages	Disadvantages
MXL Pulley (30T motor - 80T shaft)	30:80	Good speed reduction, optimal torque transfer, stable speed control	Slight complexity in aligning and tensioning belt
Direct Coupling	1:1	Simplest design, fewer components	No speed reduction, limited torque
Gearbox Reduction	Variable	High torque transfer, compact	Increased complexity, higher cost

Table 2.2 Pulley System Comparison

Evaluation:

Why 30T-80T MXL Were Selected

The 30 tooth motor pulley paired with an 80 tooth shaft pulley achieved the required speed reduction which enabled precise control of rotational speeds needed for high-quality tumbling operations. The ratio also increased torque which improved the operational efficiency of the tumbler.

Figure 2.13 MXL 80T Pulley - MXL 30T Pulley

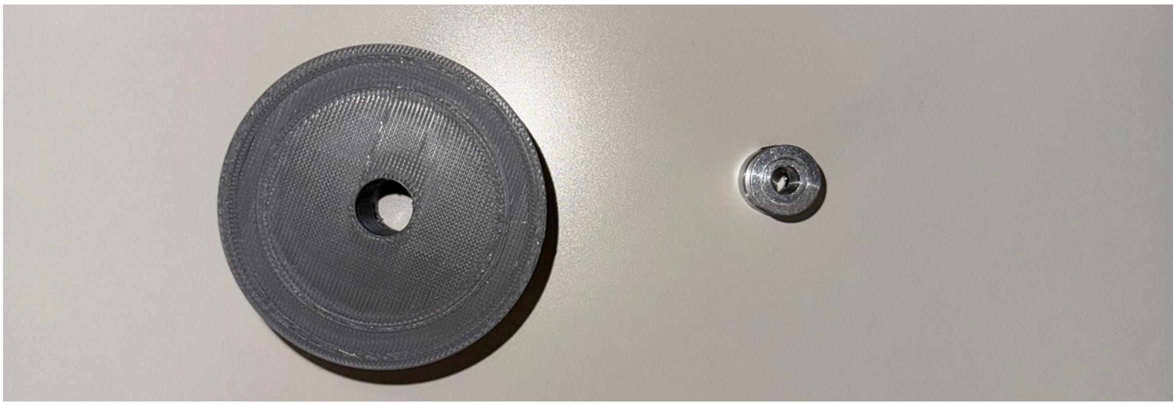

Figure 2.17 MXL 80T Pulley - MXL 30T Pulley

2.1.4. Bearing Support Comparison

Bearing Type	Load Capacity	Ease of Installation	Advantages	Disadvantages
KP000 (used)	Moderate	Easy	Simple installation, low friction, economical	Moderate load capacity
Flange Bearing	High	Moderate	Robust support, high load capacity	Slightly higher complexity
Ball Bearing (pillow-block)	High	Moderate	High precision, smooth operation	Higher cost, precision alignment required

Table 2.3 Bearing Support Comparison

Evaluation:

Why KP000 bearings Were Selected

The KP000 bearing supports were chosen because they were easy to install, could handle the loads of rotary tumbling, and were cost effective. They provided enough operational stability without making the mechanical assembly process too complicated.

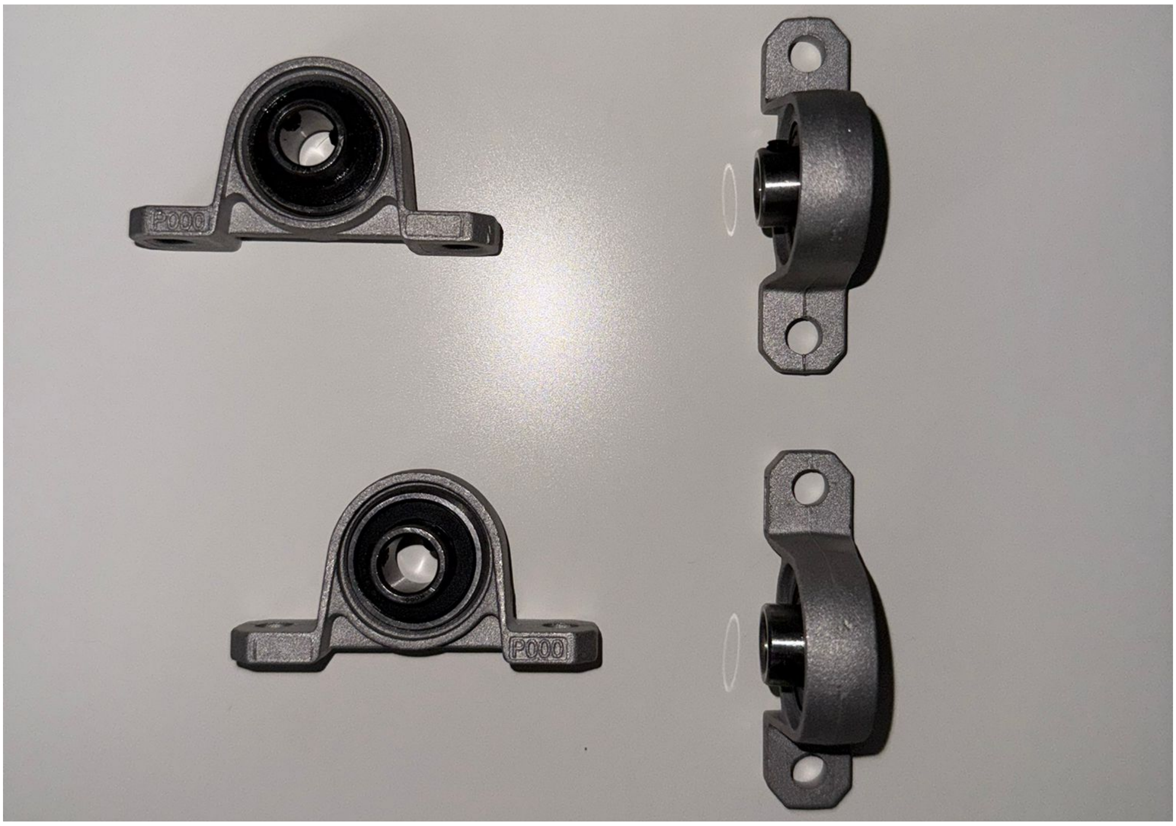

Figure 2.14 KP000 Bearings 10mm

2.1.5. Abrasive Media Types Comparison

Media Type	Abrasiveness	Material Compatibility	Advantages	Disadvantages
Walnut Shells	Mild	Metals, delicate parts	Environmentally friendly, gentle polishing, biodegradable, economical	Lower abrasive strength, slower process
Ceramic Media	High	Hard metals	Effective for heavy deburring and finishing, durable	May damage delicate parts, costly
Plastic Media	Moderate	Soft metals, plastics	Lightweight, gentle abrasion, reduced surface damage	Less durable, less effective on hard metals
Steel Media	High	Hard, resilient metals	Highly effective, quick results, durable	Risk of excessive material removal, expensive

Table 2.4 Abrasive Media Types Comparison

Evaluation :

Why Walnut Shells Were Selected

Walnut shells is selected because they possess a mild abrasive nature which makes them suitable for polishing softer metals including metal coins without causing major damage or excessive material loss. The biodegradable and environmentally friendly characteristics of walnut shells match the requirements of sustainability. The combination of walnut shells provides both effective performance and economic efficiency at a lower cost than aggressive media which makes them suitable for precision surface finishing applications studied in this research.

Although walnut shell media was initially selected for the tumbling process, ceramic media was ultimately used upon the recommendation and provision of our supervisor Prof. Dr. Aykut KENTLİ, who supplied the material directly for experimental purposes.

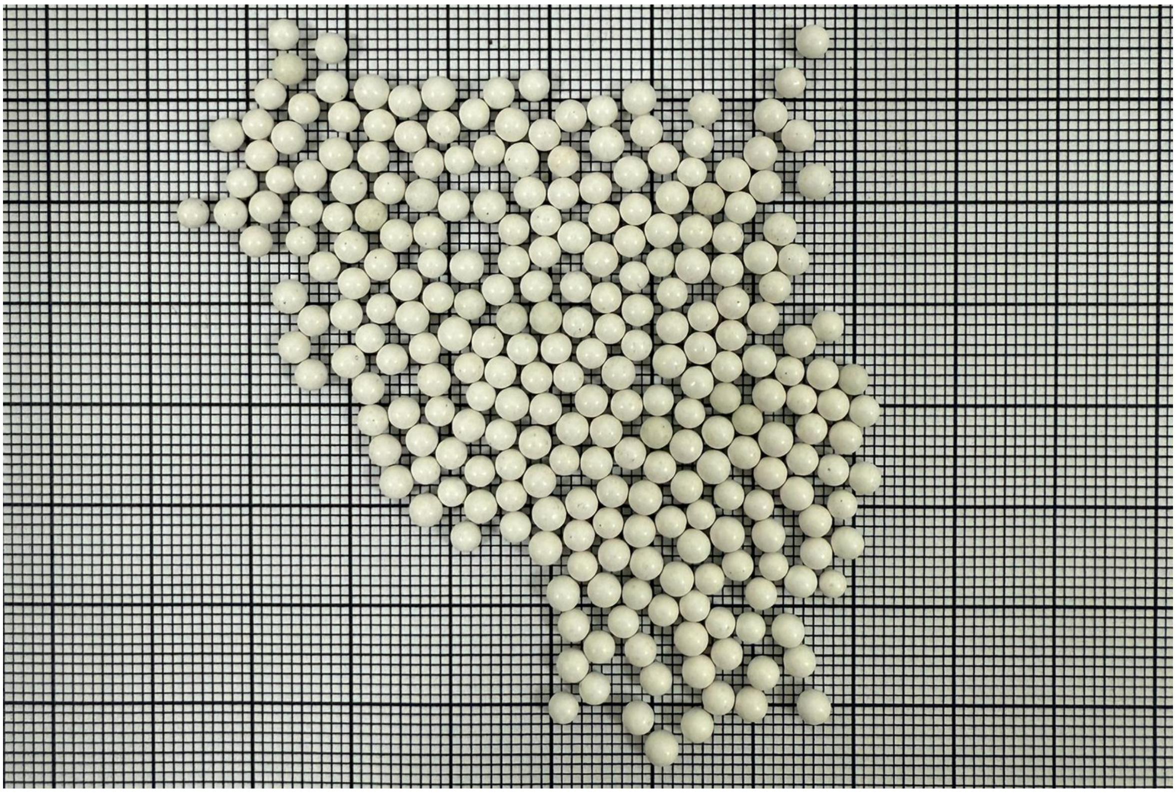

Figure 2.15 Ceramic Media

2.2. Selected Components Without Comparison

PWM Speed Controller

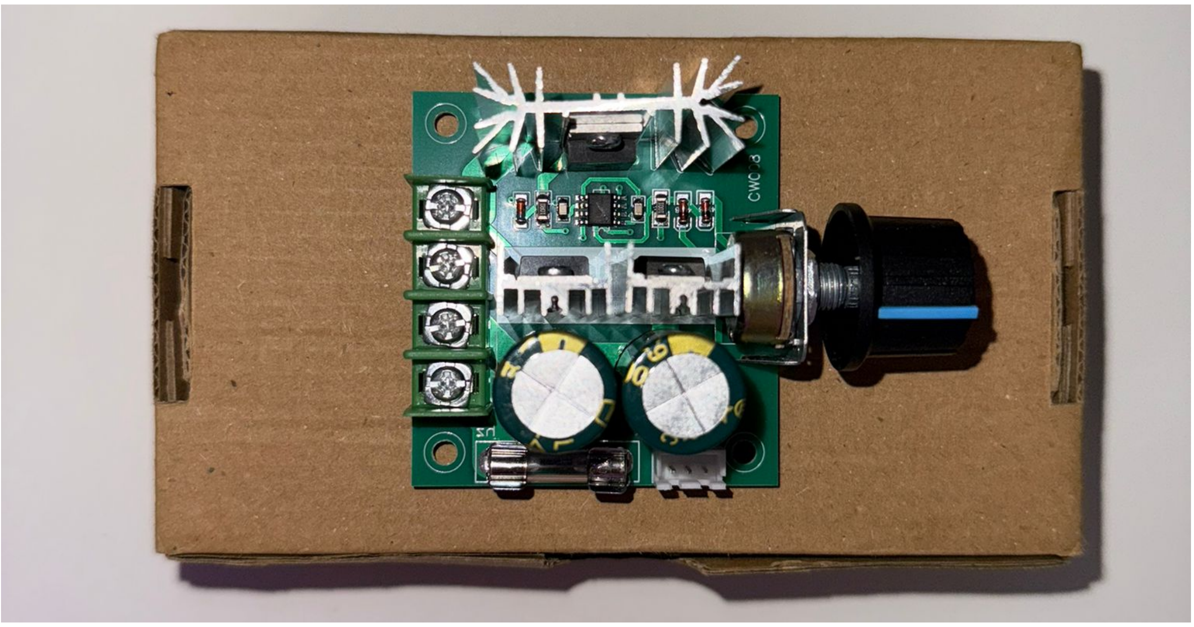

Figure 2.20 PWM Speed Controller

20x20 Sigma Profile

Figure 2.21 20x20 Sigma Profile

10mm Chrome Plated Induction Shaft 300mm

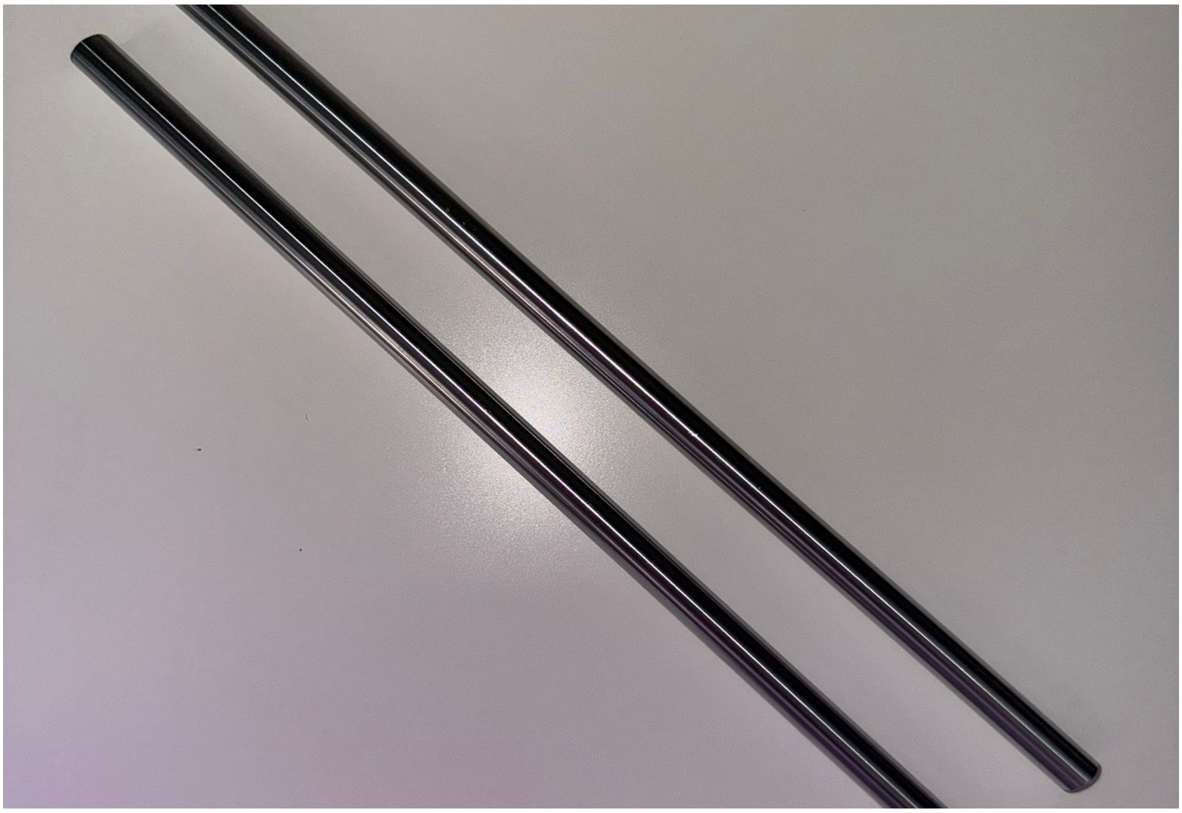

Figure 2.22 10mm Chrome Plated Induction Shaft 300mm

16GT2 Belts

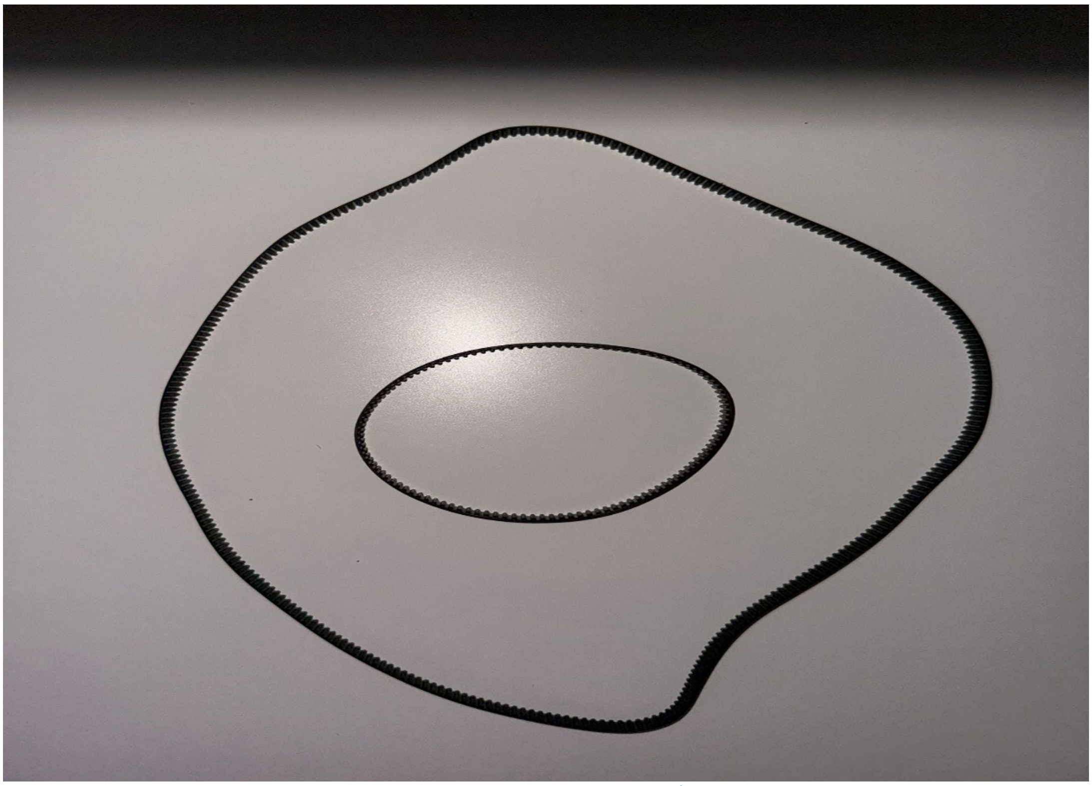

Figure 2.17 GT2 Belts

M4x8 Imbus Screw Nut and Stamp / M6/30 T Channel Nut / 20x20 Wide Corner Connection / DC Barrel Jak 2.5mm

Figure 2.18 M4x8 Imbus Screw Nut and Stamp / M6/30 T Channel Nut / 20x20 Wide Corner Connection / DC Barrel Jak 2.5mm

3. DESIGN CALCULATIONS

3.1. System Overview

The rotary tumbler is powered by a 12V DC motor operating at a nominal speed of 12,000 RPM. A 30 tooth pulley is mounted on the motor shaft and transmits rotational motion via a timing belt to a second pulley with 80 teeth, which is fixed to a 10 mm diameter shaft. This configuration reduces the speed and increases torque through the pulley ratio.

The second pulley operates on a shaft which uses two bearings to transmit power to the tumbler through an indirect system. The tumbler exists as an independent unit which does not have a fixed connection to the shaft. The tumbler receives torque transmission through surface friction because three elastic bands create frictional contact with the shaft. The system experiences energy loss through this method which we model using an efficiency factor η.

The tumbler measures 10 cm in diameter while containing about 1 kg of media for polishing or grinding purposes.

3.1.1. Shaft Speed Calculation

The speed of the shaft is determined based on the gear ratio of the pulleys:

$$RPM_{shaft} = RPM_{motor} \times \left(\frac{T_{motor}}{T_{shaft}}\right)$$

$$RPM_{shaft} = 12{,}000 \times \left(\frac{30}{80}\right) = 4500RPM$$

3.1.2. Tumbler Speed Estimation

Assuming ideal contact and minimal slippage between the elastic bands and the tumbler surface, the tumbler speed is given by:

$$RPM_{tumbler} = \eta \times RPM_{shaft} = 0.75 \times 4{,}500 = 3375RPM$$

This value is an estimate assuming good contact and tension in the elastic bands

The tumbler rotates due to frictional contact with elastic bands, the rotation rate can be estimated using a surface velocity match:

$$RPM_{tumbler} = \frac{r_{shaft}}{r_{tumbler}} \times RPM_{shaft} = \frac{0.005}{0.05} \times 3375 = 337.5RPM$$

This method assumes pure rolling without slippage. However, since three elastic bands are used for transmission, there will be some slippage and energy loss. As a result, the actual tumbler speed may be lower than 337.5 RPM depending on the tension, elasticity, and contact conditions of the bands. Thus, 337.5 RPM should be considered an upper bound.

3.1.3. Critical Speed Calculation

To avoid the tumbling medium sticking to the walls, the operating speed must remain below the critical speed N_c, calculated as:

$$N_c = \frac{60}{2\pi} \cdot \sqrt{\frac{g}{R}}$$

Where:

- $g = 9.81 m/s^2$
- $R = 0.05 m$

$$N_c = \frac{60}{2\pi} \cdot \sqrt{\frac{9.81}{0.05}} \approx 134 RPM$$

3.1.4. Froude Number Analysis for Rotary Tumbler

The Froude Number (Fr) is used to predict the tumbling regime inside the rotating drum:

$$w = \frac{2\pi N}{60} = \frac{2\pi \cdot 337.5}{60} = 35.33 rad/s$$

$$Fr = \frac{\omega^2 R}{g} g = \frac{(35.33)^2 \cdot 0.05}{9.81} = 6.37$$

This indicates a **c**entrifuging regime where the media sticks to the wall and no tumbling occurs.

Froude Number	**Regime Type**	**Behavior**
< 0.1	Slumping	Material sticks and slowly slides
0.1–1.0	Rolling/Cascading	Uniform mixing, low-energy tumbling
1.0–5.0	Cataracting	High energy tumbling, mild throwing
> 5.0	Centrifuging	Particles stick to wall, no mixing

3.1.5. RPM Comparison

$$\frac{RPM_{tumbler}}{N_c} = \frac{337.5}{134} \approx 2.52$$

The actual operating speed surpasses the critical speed which supports the centrifuging behavior. The actual RPM could be slightly lower than the measured value and closer to the acceptable range due to possible band slippage.

3.1.6. Force Calculation

To calculate the total force exerted by the rotating mass (1 kg) on the tumbler wall:

Angular velocity:

$$w = 2\pi \cdot \frac{337.5}{60} = 35.33 rad/s$$

Centrifugal force:

$$F_c = m \cdot R \cdot w^2 = 1 \cdot 0.05 \cdot (35.33)^2 = 62.39N$$

Gravitational force:

$$F_g = m \cdot g = 1 \cdot 9.81 = 9.81N$$

Total resultant force:

$$F_{total} = \sqrt{F_c^2 + F_g^2} = \sqrt{(62.89)^2 + 9.81^2} = 63.2N$$

This is the combined load experienced by the tumbler wall and transmitted to the shaft via friction and the support bearings.

3.1.7. Shaft Strength and Deflection Analysis

The assessment of the 10 mm diameter, 200 mm long aluminum shaft's ability to support the tumbler under operational loads requires analysis of bending stress, safety factor, shaft deflection, and critical speed.

Maximum bending moment:

The maximum bending moment for a centrally loaded simply supported beam is given by:

$$M = \frac{F_{total} \cdot L}{4} = \frac{63.2 \cdot 0.2}{4} = 3.16Nm$$

Section Modulus

For a circular shaft, the section modulus is:

$$S = \frac{\pi d^3}{32} = \frac{\pi(0.01)^3}{32} = 9.82 \times 10^{-8} m^3$$

Bending Stress:

$$\sigma = \frac{M}{S} = \frac{3.16}{9.82 \times 10^{-8}} = 32.17 MPa$$

This stress is well below the yield strength of aluminum (100 MPa), indicating the shaft will not fail under bending.

Safety Factor:

$$SF = \frac{\sigma_{yield}}{\sigma} = \frac{100}{32.17} = 3.11$$

This safety factor is acceptable but close to the lower limit for rotating mechanical systems, which typically require a minimum factor of 3–5 due to dynamic effects.

Shaft Deflection:

Maximum deflection at the shaft center is given by:

$$\delta = \frac{F \cdot L^3}{48 \cdot E \cdot I}$$

Where the moment of inertia is:

$$I = \frac{\pi \cdot d^4}{64} = \frac{\pi \cdot (0.01)^4}{64} = 4.91 \times 10^{-11} m^4$$

Substituting values:

$$\delta = \frac{63.2 \cdot (0.2)^3}{48 \cdot 70 \times 10^9 \cdot 4.91 \times 10^{-11}} \approx 1.52 mm$$

3.1.8. Critical Shaft Speed

To avoid resonance and ensure safe operation, the critical speed is computed using the simplified Euler-Bernoulli beam formula:

$N_{critical} = \frac{1}{2\pi} \cdot \sqrt{\frac{48EI}{mL^3}}$ (for simply supported shaft)

$$N_{critical} = \frac{1}{2\pi} \cdot \sqrt{\frac{48 \cdot (70 \times 10^9) \cdot (4.91 \times 10^{-11})}{m \cdot (0.2)^3}} = 137.3RPM$$

Operational tumbler speed is 337.5 RPM

Critical shaft speed is 137.3 RPM

Resultant Dynamic Load per Bearing:

$$F_{r,bearing} = \frac{F_{total}}{4} = 15.8N$$

3.1.9. Dynamic Load Rating and Bearing Life Evaluation

To ensure long-term reliability of the KP000 bearings used in the rotary tumbler, we evaluate the required dynamic load rating C_{10} based on the system's load, speed, and desired life.

The life is to be 30000 h. Exhibit a reliability of 0,90, application factor is 1.4 and a = 10/3 for cylindrical roller bearing. Manufacturer's rating life is 10^6 revolutions.

$$C_{10} = a_f F_D \left\{ \frac{x_D}{x_0 + (\theta - x_0)\left[\ln\left(\frac{1}{R_D}\right)^{\frac{1}{b}}\right]} \right\}^{\frac{1}{a}}$$

Using Weibull parameters as $x_0 = 0.02$, $\theta - x_0 = 4.439$ and $b = 1.483$

$$x_0 + (\theta - x_0)\left[\ln\left(\frac{1}{R_D}\right)^{\frac{1}{b}}\right] = 0.02 + 4.439 \cdot \left[\ln\left(\frac{1}{0.90}\right)\right]^{0.674} \approx 1.098$$

$$x_D = \frac{L_D}{L_{10}} = \frac{60 \cdot 30000 \cdot 337.5}{10^6} = 607.5$$

$$C_{10} = a_f \cdot F_D \cdot x_D^{1/a} = 1.4 \cdot 15.8 \cdot (607.5)^{3/10} = 151.304N$$

Since the load is applied at two bearing locations, the total equivalent requirement is: $C_{10,total} = 2 \cdot C_{10} = 302.608N$

To ensure safety under dynamic conditions, a safety factor of 1.5 is applied:

$$C_{10,required} = 1.5 \cdot C_{10,total} = 453.912N$$

The KP000 bearing must have a minimum basic dynamic load rating of 454 N to achieve 30,000 hours of service life at 337.5 RPM with 90% reliability. The C10 rating of KP000 bearings exceeds 4600 N which meets the calculated requirement.

4. 3D MODELLING

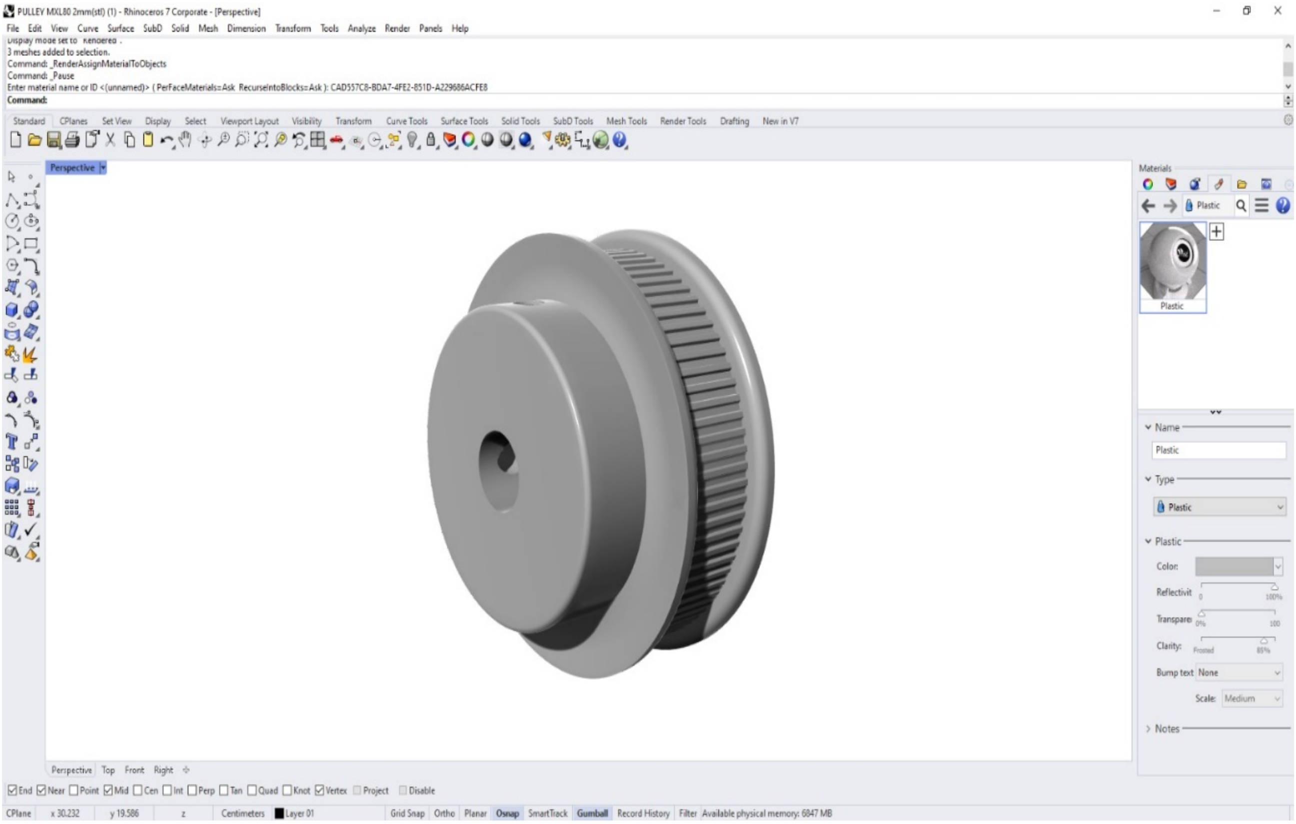

Figure 4.19 3D Model of MXL 80T Pulley

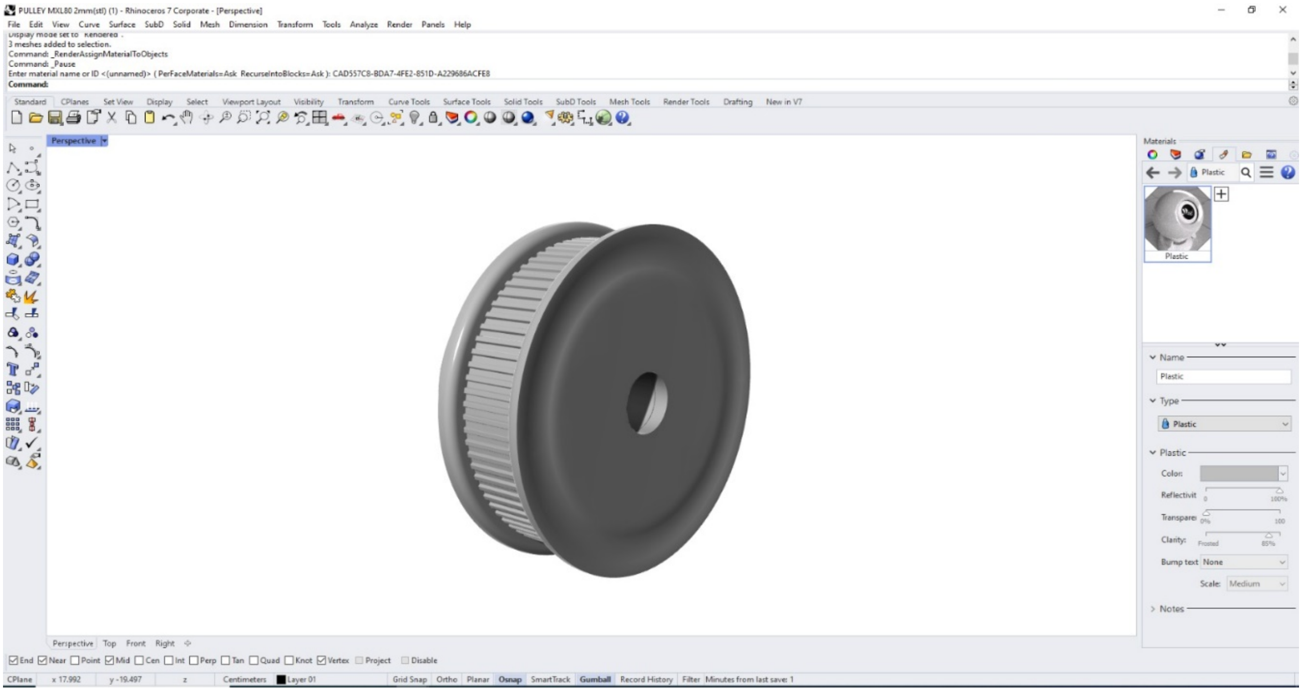

Figure 4.20 3D Model of MXL 80T Pulley

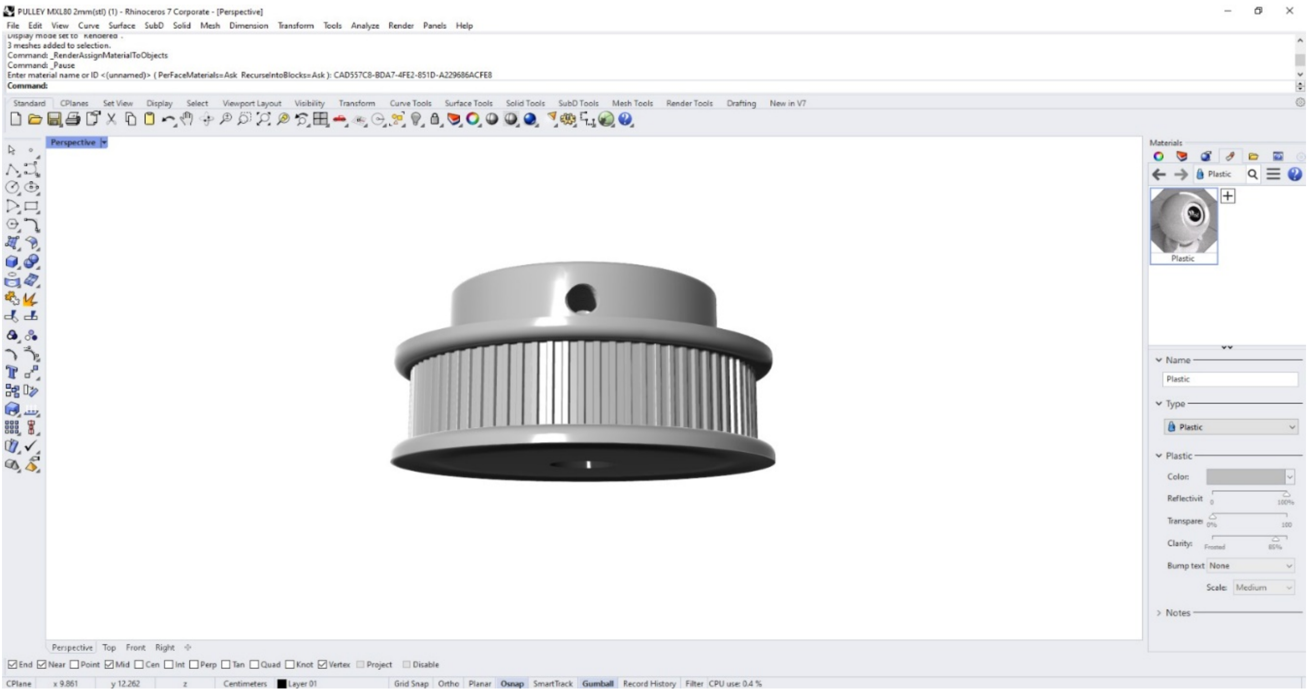

Figure 4.27 3D Model of MXL 80T Pulley

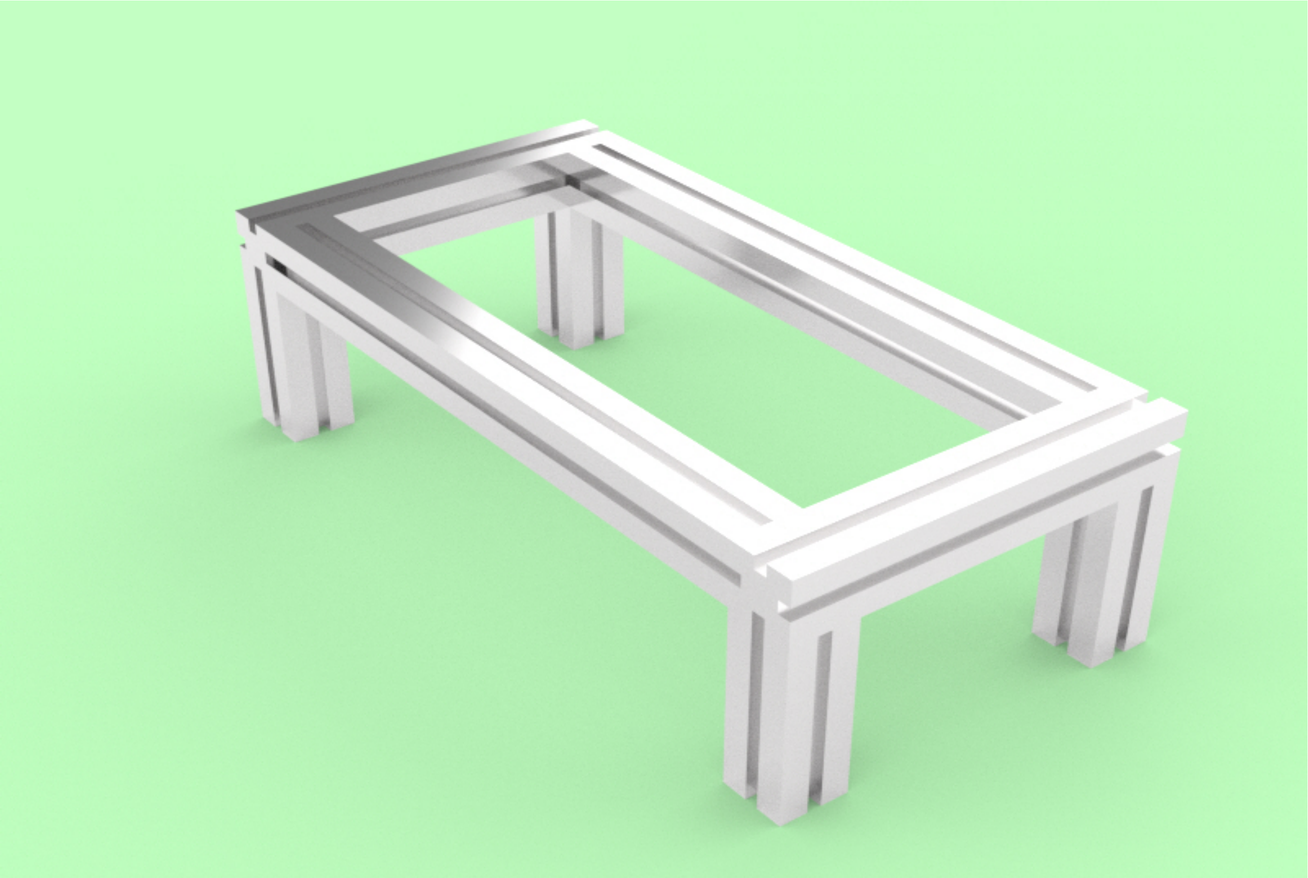

Figure 4.21 3D Model of Case Made With Aluminum

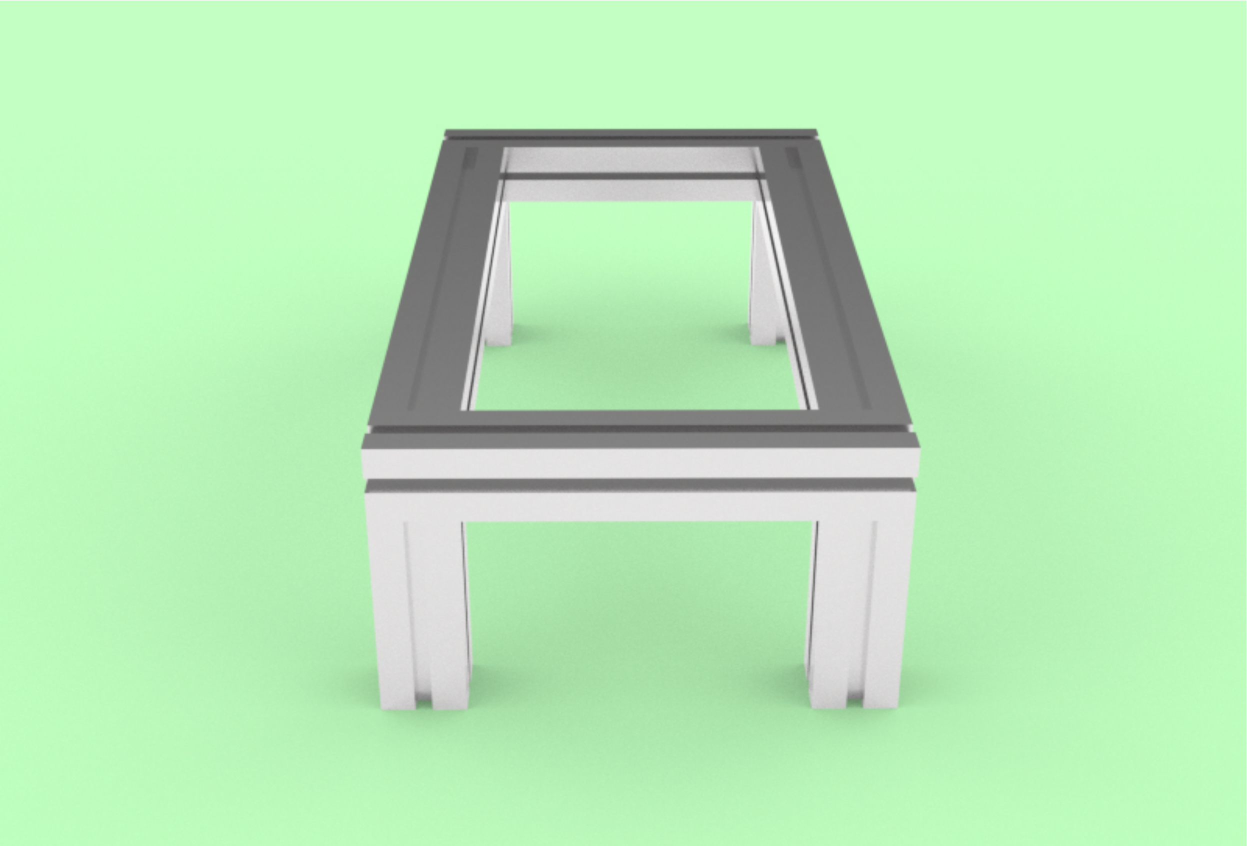

Figure 4.22 3D Model of Case Made With Aluminum

Figure 4.30 3D Model of Case Made With Aluminum

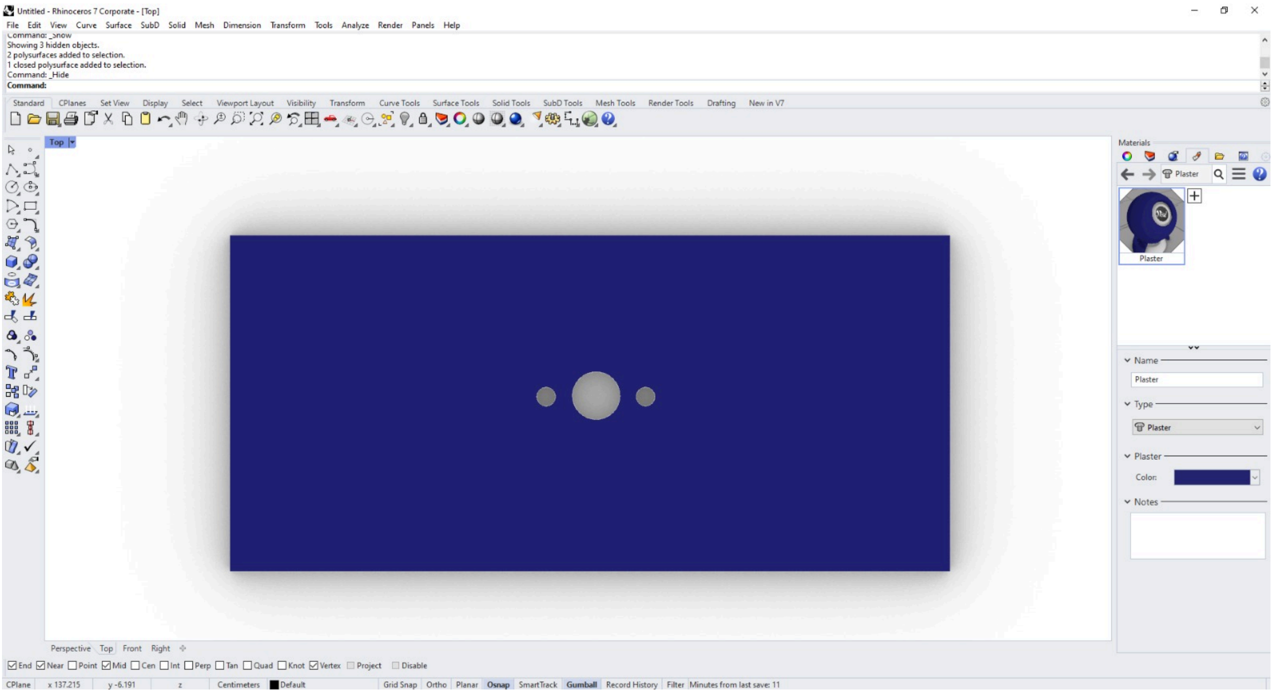

Figure 4.31 3D Model of MDF Side Plate

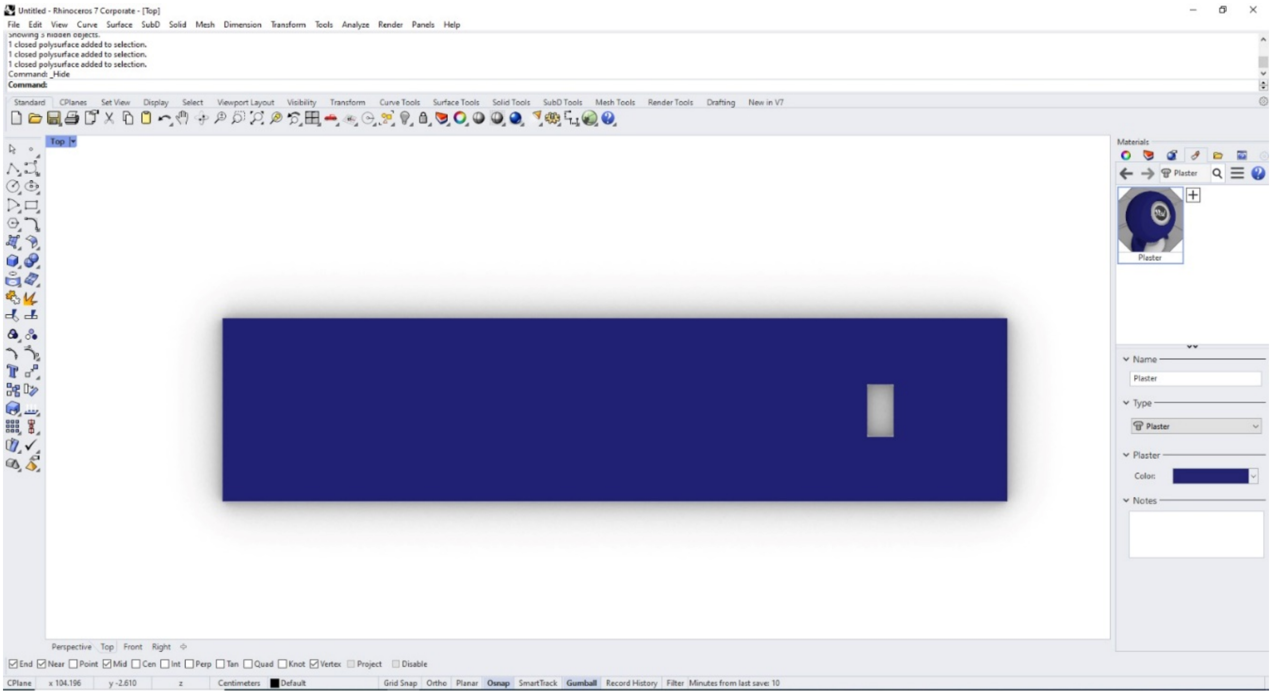

Figure 4.32 3D Model of MDF Side Plate

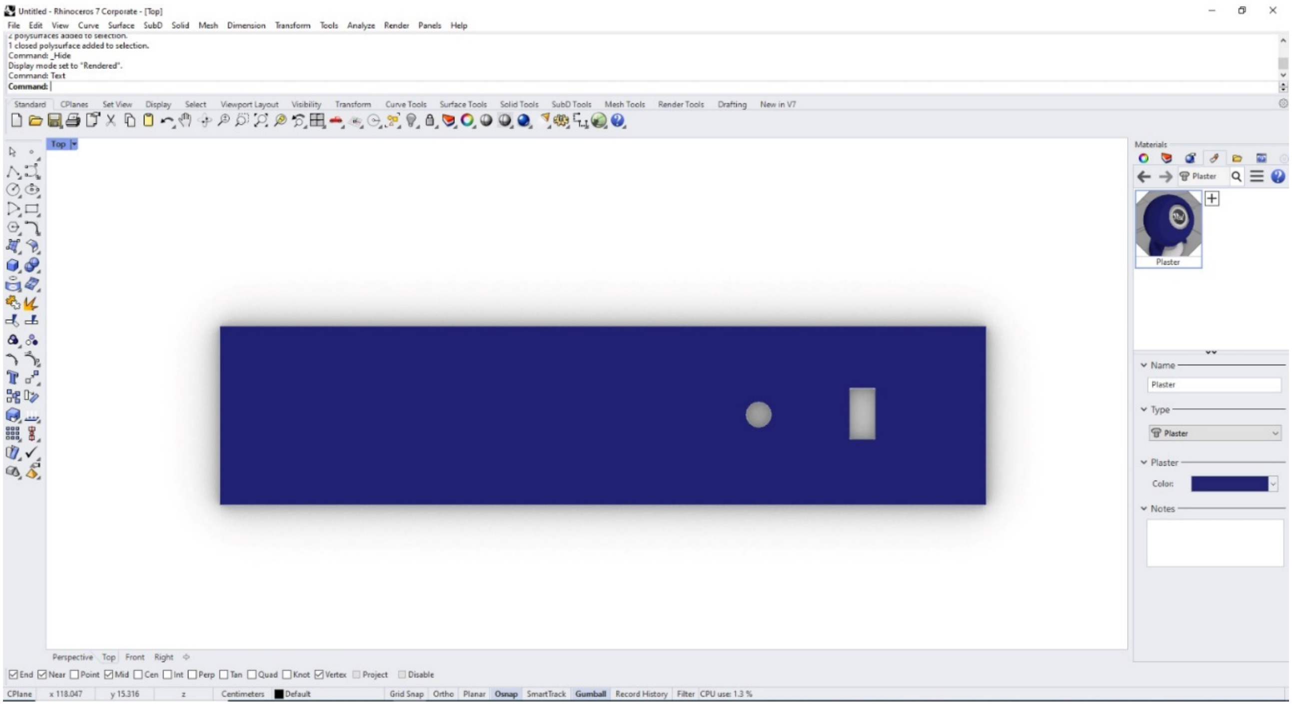

Figure 4.23 3D Model of MDF Side Plate

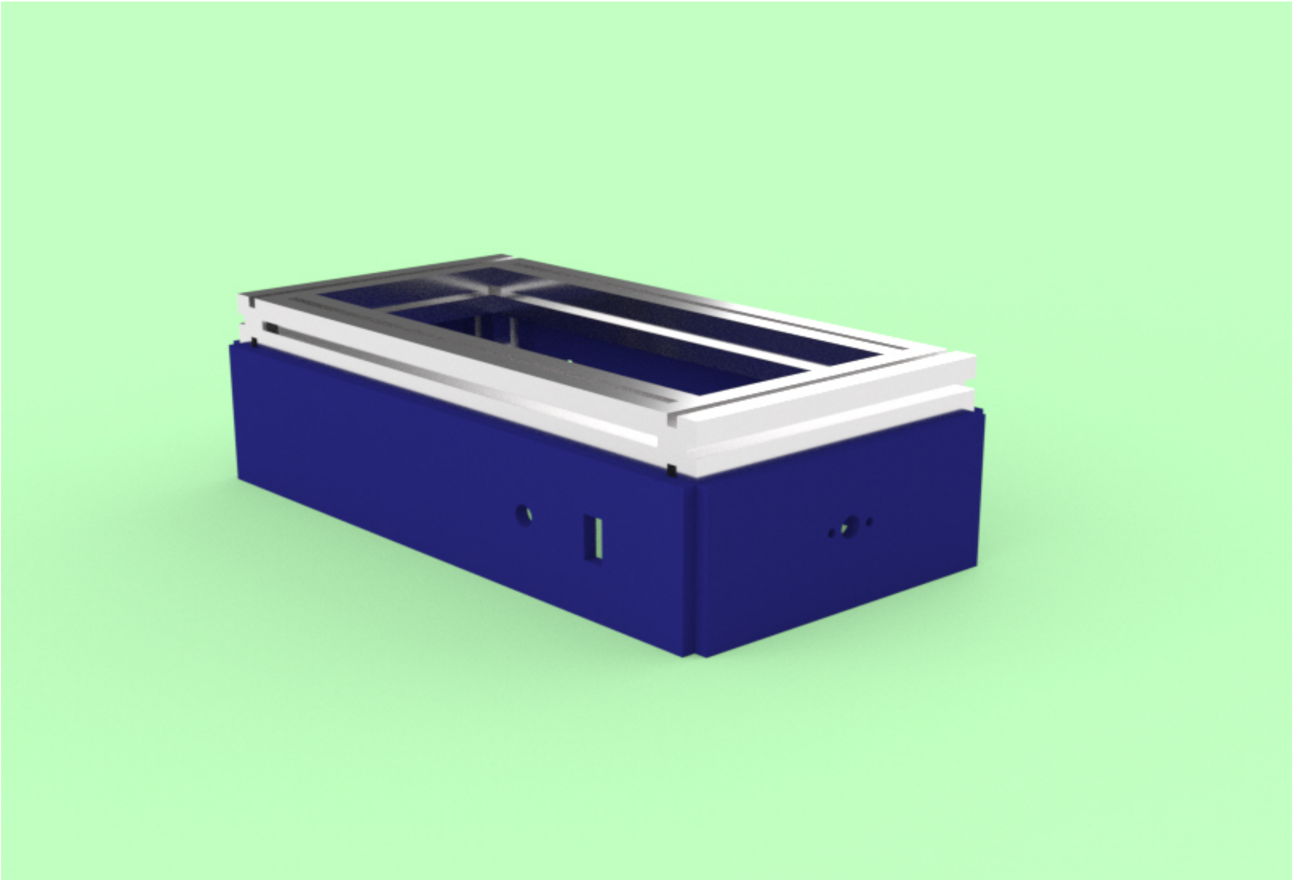

Figure 4.24 3D Model of MDF Side Plate With Case

All the drawings were made by me in the RHINO7

5. METHODOLOGY AND EXPERIMENTAL RESULTS

5.1. Experimental Setup

The experimental apparatus consisted of:

- The DC Motor (RS775) reached 12000 RPM when powered by a 12 V DC motor. The PWM DC motor speed controller (rated at 12V-40V, 10A, and 400W) operated on an adjustable power supply (3V-12V, 10A) to control the motor speed.
- The system used a 30 tooth MXL timing pulley as its connection point. The pulley system transmitted rotational motion to an 80 tooth pulley which used a GT2 type 610 mm timing belt to drive the tumbler shaft with precise speed control.
- Two metal shafts with 10 mm diameter and 300 mm length were used in the experiment. The 80 tooth pulley transmitted rotational motion to the tumbler chamber through a direct connection. The second shaft functioned as a support shaft which received power indirectly from the motor to maintain both structural

stability and balanced rotation. The two shafts received support from KP000 bearing supports to achieve smooth and stable rotation.

- The cylindrical tumbling chamber contained both walnut shells and metal coins as part of its design. The chamber dimensions allowed media specimens to move freely which resulted in the best possible surface finishing outcomes.

5.1.1. Materials and Media

- Specimen: Standard metal coins were selected as specimens for their uniform size and surface characteristics, facilitating consistent evaluation and comparison of surface finishing results.
- Abrasive Media: The choice of walnut shells as an environmentally friendly abrasive was based on their gentle polishing properties, their ability to work with soft metals, biodegradability and cost-effectiveness.
- **We use ceramic media.**

5.1.2. Experimental Parameters

The following parameters were investigated:

- Rotational Speed (RPM): The theoretical tests of multiple rotational speeds were conducted between 30 RPM and 120 RPM because of the pulley system's gear reduction.
- Tumbling Duration: Systematic evaluations of tumbling durations were conducted which ranged from 15 minutes to 120 minutes.
- Media-to-Material Ratio: We conducted different ratios to determine their effect on polishing efficiency and surface quality by using ratios from 1:1 to 5:1.

5.1.3. Study on Surface Area Reduction Using a Rotary Tumbler

The experimental study employed a rotary tumbler system to assess ceramic media surface abrasion performance at various rotational speeds. The DC motor operated at 12,000 RPM while the motor speed controller divided into 240 steps allowed researchers to select rotational speeds proportionally up to 215 max. Three target speed values were established at 50, 70 and 90 based on this defined range.

For each speed setting, a unique set of 10 rusted screws was selected, resulting in a total of 30 distinct samples being tested throughout the experiment. These screw groups were not reused across different speeds, ensuring that each group represented an independent test condition.

Each group was subjected to a total of 45 minutes of tumbling, divided into three consecutive 15-minute intervals. After each interval (15, 30, and 45 minutes), the screws were removed and photographed under consistent lighting and positioning conditions to capture changes in surface area.

Surface area measurements were conducted using ToupView image analysis software, which allowed precise area quantification from photographs. To improve measurement reliability, each screw group was analyzed twice using the same software. Due to subtle differences in image processing sensitivity, two slightly different results were obtained for each screw group, despite identical input images and conditions.

Therefore, for every speed setting, two separate result tables were created, each based on an independent ToupView analysis of the same 10 screws. Afterward, an average of the two datasets was calculated to represent the result for each speed setting. These averaged results were used to produce the performance comparison graphs and surface loss evaluations presented in the following sections.

5.2. RESULTS

First Group At 50 Speed

Sample 1 Surface Area Loss At 50						
Screw No	**Before (mm^2)**	**After 15 min (mm^2)**	**After 30 min (mm^2)**	**After 45 min (mm^2)**	**Loss (mm^2)**	**Loss (%)**
1	58,035	57,086	56,5549	56,238	1,797	3,0965
2	57,5	56,4253	56,122	55,2695	2,2305	3,8791
3	56,965	55,8346	55,569	54,9292	2,0358	3,5738
4	56,429	55,4308	55,0293	54,3631	2,0659	3,661
5	55,894	54,9658	54,2858	53,8295	2,0645	3,6936
6	55,359	54,4186	53,8483	53,4175	1,9415	3,5071
7	54,824	54,1973	53,5721	52,977	1,847	3,3689
8	54,289	53,6041	52,6934	52,276	2,013	3,708
9	53,754	53,1891	52,4997	51,7189	2,0351	3,786
10	53,219	52,3943	51,6279	51,2793	1,9397	3,6447
Average	55,6268	54,75459	54,18024	53,6298	1,997	3,59187

Table 5.5 Group 1 Surface Area Loss At 50 2. Analysis

Sample 1 Surface Area Results at 50 2.Analysis						
Screw No	Trial 2 - Before (mm²)	After 15 min (mm²)	After 30 min (mm²)	After 45 min (mm²)	Loss (mm²)	Loss (%)
1	58,281	57,6562	56,7672	56,2607	2,0203	3,4665
2	55,094	54,3117	53,7183	53,4289	1,6651	3,0223
3	53,312	52,3458	51,8527	51,2984	2,0136	3,777
4	52,932	52,349	51,4028	51,0123	1,9197	3,6267
5	53,955	52,9825	52,5827	52,0578	1,8972	3,5163
6	56,381	55,6893	55,1565	54,574	1,807	3,205
7	60,21	59,0869	58,637	58,0122	2,1978	3,6502
8	61,442	60,2784	60,1782	59,2262	2,2158	3,6063
9	62,077	61,3588	60,7249	59,7316	2,3454	3,7782
10	60,115	59,302	58,334	57,7842	2,3308	3,8772
Average	57,3799	56,53606	55,93543	55,33863	2,04127	3,55257

Table 5.6 Group 1 Surface Area Loss At 50 2. Analysis

Avarage of 2 Analysis						
Screw No	Before (mm²)	After 15 min (mm²)	After 30 min (mm²)	After 45 min (mm²)	Loss (mm²)	Loss (%)
1	55.804	55.153	54.728	54.491	1.313	2.353
2	55.790	54.890	54.563	54.036	1.754	3.144
3	54.954	54.193	53.658	53.342	1.612	2.934
4	59.449	58.317	57.792	57.229	2.220	3.733
5	55.369	54.680	54.168	53.618	1.751	3.163
6	58.517	57.111	56.677	56.027	2.490	4.254
7	56.598	55.728	55.110	54.453	2.145	3.789
8	59.148	58.044	57.593	56.986	2.162	3.655
9	58.932	58.010	57.447	56.642	2.290	3.887
10	55.598	54.298	53.892	53.473	2.125	3.823
Average	57.016	56.042	55.563	55.030	1.986	3.474

Table 5.7 Average of 2 Analysis at 50 Speed

The table shows the surface area measurements of ten different screws when they were tested at a 50 speed rotary tumbler setting. The screws underwent three consecutive tumbling periods of 15 minutes each for a total duration of 45 minutes. Surface area measurements were recorded at 15 minute intervals. Two separate image analyses were conducted for each screw using the ToupView software. The table presents the average results from two independent measurements.

The abrasion process at this speed resulted in a moderate but consistent reduction in surface area across all samples. The average material loss remained within controlled limits, typically below 4%. The 50 speed configuration produced gentle yet effective polishing which made it appropriate for surfaces needing dimensional stability without excessive material removal.

Second Group At 70 Speed

Sample 2 Surface Area Results at 70						
Screw No	Trial 3 - Before (mm²)	After 15 min (mm²)	After 30 min (mm²)	After 45 min (mm²)	Loss (mm²)	Loss (%)
1	53,0792	51,7022	50,7855	49,4313	3,6479	6,8726
2	52,8995	51,5639	50,3019	49,5771	3,3224	6,2806
3	54,4936	53,0351	51,8389	50,387	4,1066	7,5359
4	62,0108	60,717	58,9331	57,8215	4,1893	6,7558
5	57,4866	55,8042	54,6704	53,4877	3,9989	6,9562
6	61,8046	60,0977	59,1527	57,2112	4,5934	7,4321
7	57,0692	55,7925	53,9267	52,9772	4,092	7,1702
8	62,7355	61,3746	60,0993	57,8485	4,887	7,7898
9	52,3734	50,9139	49,8827	49,1081	3,2653	6,2347
10	54,7097	53,1037	51,5172	51,4175	3,2922	6,0176
Average	56,86621	55,41048	54,11084	52,92671	3,9395	6,90455

Table 5.8 Group 2 Surface Area Loss At 70

Sample 2 Surface Area Results at 70 2.Analysis						
Screw No	Trial 4 - Before (mm²)	After 15 min (mm²)	After 30 min (mm²)	After 45 min (mm²)	Loss (mm²)	Loss (%)
1	56,9583	55,6855	53,5507	53,1972	3,7611	6,6033
2	62,6378	61,2505	59,6512	58,5063	4,1315	6,5959
3	62,2524	60,7652	58,9486	58,2109	4,0415	6,4921
4	58,9965	57,7207	56,3519	54,8211	4,1754	7,0774
5	57,7773	56,3491	55,0063	53,3548	4,4225	7,6544
6	58,901	57,162	56,1207	54,6084	4,2926	7,2878
7	59,534	57,982	56,083	54,9995	4,5345	7,6167
8	62,1803	60,6865	59,5659	58,1864	3,9939	6,4231
9	59,3861	57,8889	56,7256	54,8586	4,5275	7,6238
10	52,1059	50,9303	49,6801	48,935	3,1709	6,0855
Average	59,07296	57,64207	56,1684	54,96782	4,10514	6,946

Table 5.9 Group 2 Surface Area Loss At 70 2. Analysis

Avarage of 2 Analysis						
Screw No	Trial 4 - Before (mm²)	After 15 min (mm²)	After 30 min (mm²)	After 45 min (mm²)	Loss (mm²)	Loss (%)
1	58.651	57.226	56.218	55.393	3.258	5.556
2	59.226	57.680	56.776	55.855	3.371	5.689
3	58.044	56.638	55.676	54.884	3.160	5.443
4	60.802	59.142	57.863	56.709	4.093	6.730
5	57.659	56.319	55.532	54.688	2.971	5.152
6	59.415	57.841	56.772	55.773	3.642	6.130
7	57.489	55.934	54.914	54.080	3.409	5.927
8	58.998	57.374	56.414	55.487	3.511	5.951
9	59.369	57.755	56.893	56.064	3.305	5.566
10	58.732	57.136	56.084	55.212	3.520	5.996
Average	58.839	57.305	56.314	55.415	3.424	5.814

Table 5.10 Average of 2 Analysis at 70 Speed

The results from a surface area analysis of ten new screws at 70 speed are presented in the table. The same procedure as before was followed for each screw which included three 15-minute tumbling stages and ToupView software measurements at each stage. The data presented represents the combined results of two independent trials.

The 70 speed condition produced the greatest surface area reduction among all tested speeds. All samples showed substantial uniform wear patterns which resulted in surface losses above 5% and reached a maximum of 6.73%. The uniform surface area reduction pattern across all screws indicates that the 70 speed setting delivers the best combination of abrasive energy and contact frequency for aggressive surface treatment.

Third Group At 90 Speed

Sample 3 Surface Area Results at 90						
Screw No	Trial 5 - Before (mm²)	After 15 min (mm²)	After 30 min (mm²)	After 45 min (mm²)	Loss (mm²)	Loss (%)
1	58,0013	56,6767	56,3959	56,0633	1,938	3,3413
2	53,6239	52,4536	52,209	51,8464	1,7775	3,3148
3	54,6806	53,4603	53,1013	52,6546	2,026	3,7052
4	58,9929	58,2198	57,5746	57,245	1,7479	2,9629
5	56,0024	56,0024	56,2439	55,9064	1,8049	3,1275
6	58,4061	56,7543	56,6599	56,1201	2,286	3,914
7	57,1651	56,0743	55,8916	55,487	1,6781	2,9355
8	56,6055	55,1421	55,0192	54,3141	2,2914	4,048
9	59,5544	58,4847	58,1237	57,5397	2,0147	3,383
10	57,0677	55,6953	55,4743	55,3588	1,7089	2,9945
Average	57,00999	55,89635	55,66934	55,25354	1,92734	3,37267

Table 5.11 Group 3 Surface Area Loss At 90

Sample 3 Surface Area Results at 90						
Screw No	Trial 6 - Before (mm²)	After 15 min (mm²)	After 30 min (mm²)	After 45 min (mm²)	Loss (mm²)	Loss (%)
1	57,6447	57,0678	56,1934	56,2474	1,3973	2,424
2	61,7169	60,8696	60,4457	59,5529	2,164	3,5063
3	59,1877	58,3124	57,8447	57,3698	1,8179	3,0714
4	59,7635	58,6337	58,5533	58,5018	1,2617	2,1112
5	55,8146	54,4655	54,6511	53,271	2,5436	4,5572
6	60,3817	58,9116	58,7708	58,7708	1,6109	2,6679
7	56,4136	55,6745	54,831	54,0016	2,412	4,2756
8	61,6562	59,9895	60,4147	59,6924	1,9638	3,1851
9	58,1505	56,4784	56,5812	56,2365	1,914	3,2915
10	54,3881	53,8388	52,8799	51,674	2,7141	4,9902
Average	58,51175	57,42418	57,11658	56,53182	1,97993	3,40804

Table 5.12 Group 3 Surface Area Loss At 90 2. Analysis

Avarage of 2 Analysis						
Screw No	Before (mm²)	After 15 min (mm²)	After 30 min (mm²)	After 45 min (mm²)	Loss (mm²)	Loss (%)
1	57.823	56.872	56.295	56.155	1.668	2.883
2	57.670	56.662	56.327	55.700	1.971	3.411
3	56.934	55.886	55.473	55.012	1.922	3.388
4	59.378	58.427	58.064	57.773	1.505	2.538
5	55.908	55.234	55.448	54.589	2.174	3.842
6	58.408	56.983	56.667	56.115	2.293	3.926
7	56.789	55.874	55.361	54.744	2.045	3.606
8	59.131	57.566	57.631	56.770	2.128	3.616
9	58.830	57.916	57.553	56.940	1.890	3.211
10	55.728	54.429	54.177	53.881	1.847	3.397
Average	57.660	56.585	56.300	55.768	1.944	3.382

Table 5.13 Average of 3 Analysis at 90 Speed

Ten new screws were tested at 90 speed. As in previous tests, ToupView software was used for dual image based measurements at three time intervals. The values listed represent the average surface area for each screw.

Contrary to expectations, the 90 speed configuration did not yield the highest material removal. Although the system operated at higher speed, the average surface area loss was lower than that observed at 70 speed and, in some cases, comparable to the 50 speed results. This phenomenon may be attributed to reduced effective contact between the ceramic media and the sample surface due to excessive centrifugal motion. As a result, the 90 speed setting appears to be less efficient for controlled abrasion tasks.

5.2.1. Comparison of Surface Area Reduction at Different Speeds

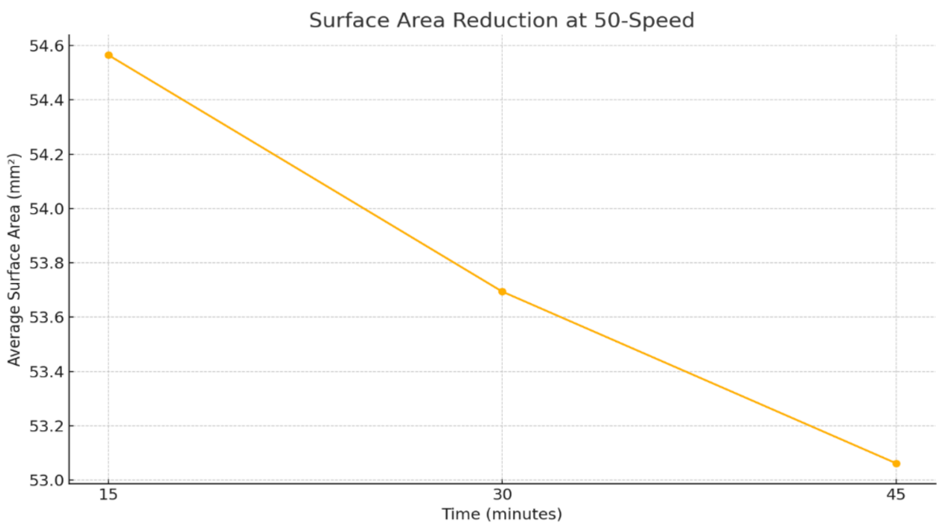

Figure 5.25 Surface Area Reduction At 50 Speed

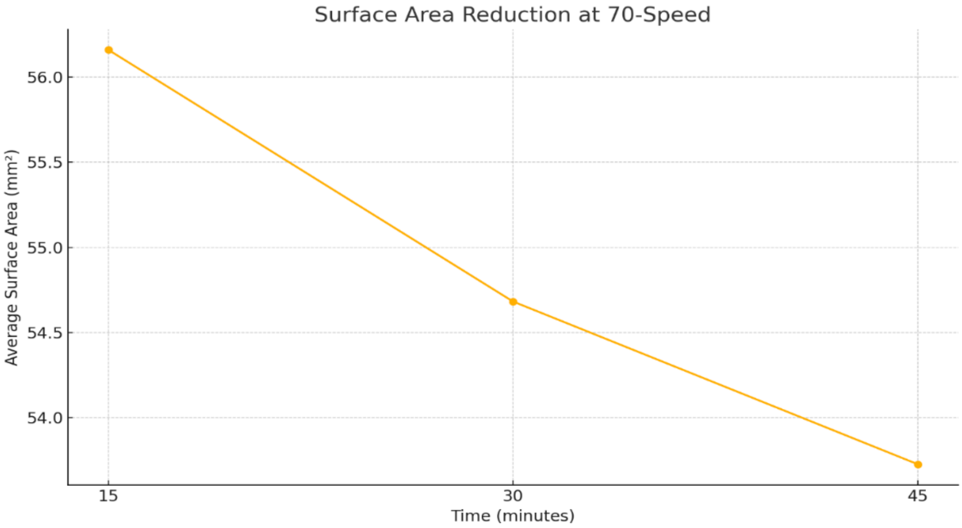

Figure 5.26 Surface Area Reduction At 70 Speed

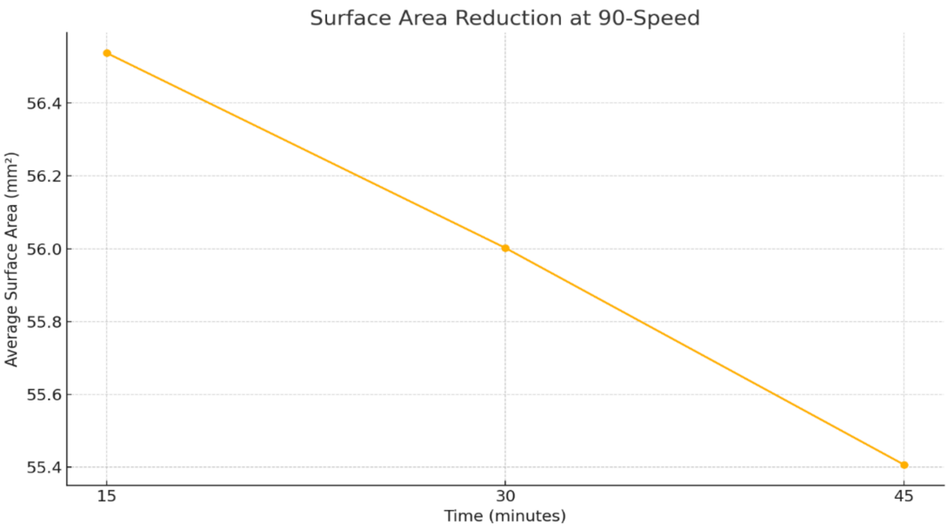

Figure 5.27 Surface Area Reduction At 90 Speed

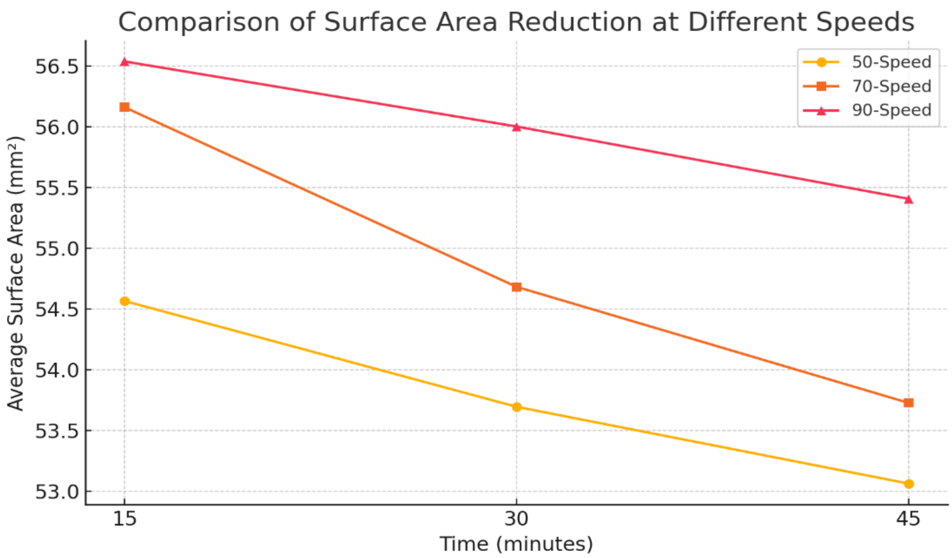

Figure 5.28 Comparison of Surface Area Reduction at Different Speeds

This table illustrates the average surface area reduction over time for three different rotary tumbler speed settings. The 70 speed setting demonstrated the steepest and most consistent decline in surface area, indicating superior abrasive efficiency. In contrast, the 90 speed trial exhibited a slower rate of surface loss despite higher rotation, suggesting diminished contact effectiveness. The 50 speed setting resulted in the least aggressive but most stable polishing effect.

Therefore, 70 speed was identified as the most effective configuration for achieving significant and uniform surface abrasion. Also we can calculate the rpm for these speed values.

50 Speed:

$$(\frac{50}{215}) \times 12000 \approx 2790\ rpm$$

70 Speed:

$$(\frac{70}{215}) \times 12000 \approx 3907\ rpm$$

90 Speed:

$$(\frac{90}{215}) \times 12000 \approx 5023\ rpm$$

Speed Setting	**Control Value (0–215)**	**Approximate RPM**
50	50	2790 rpm
70	70	3907 rpm
90	90	5023 rpm

Table 5.14 Corresponding Rotational Speeds

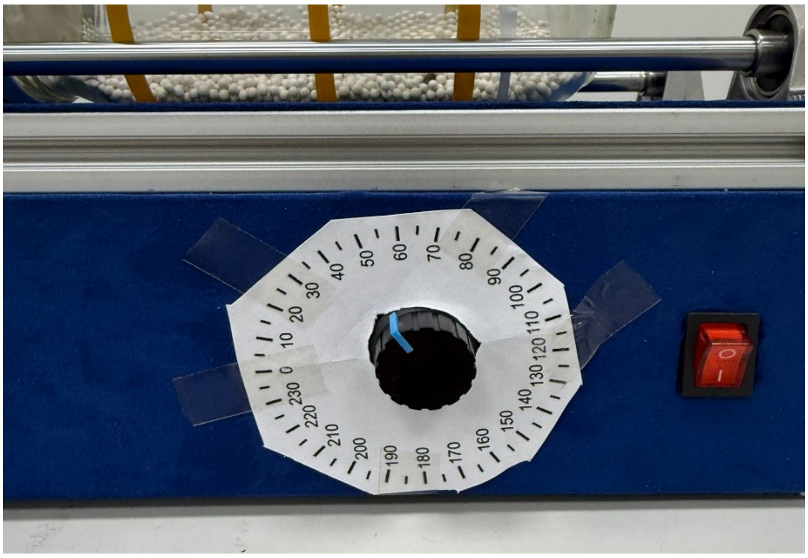

Figure 5.29 Handmade speed measurement scale

Calibration For ToupView Software

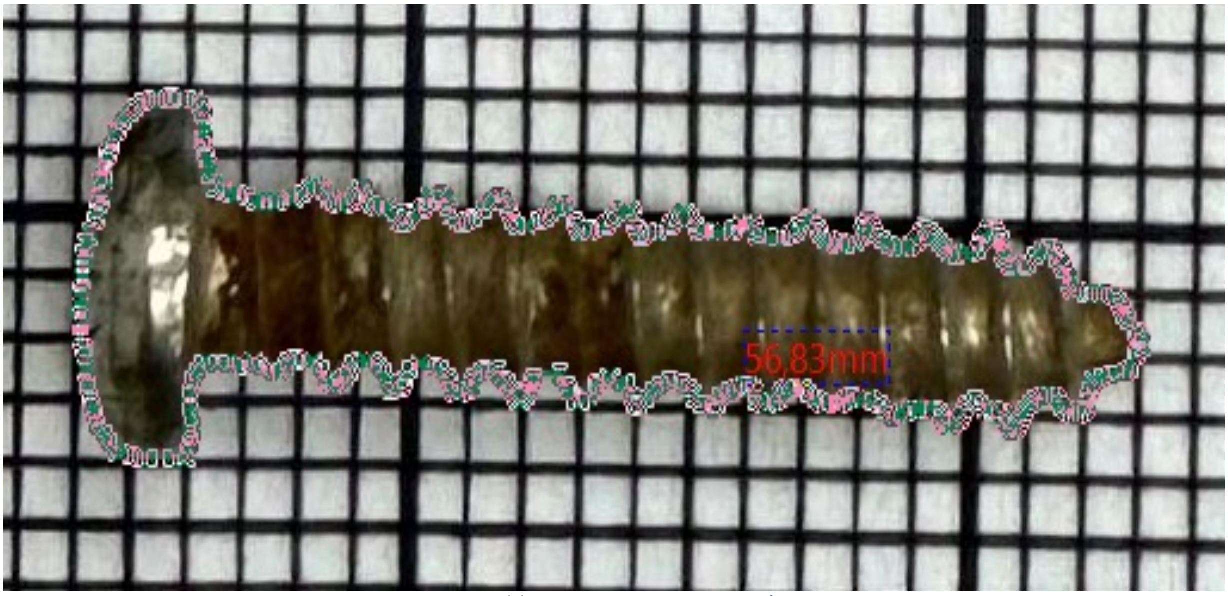

Figure 5.30 Calibration For ToupView Software

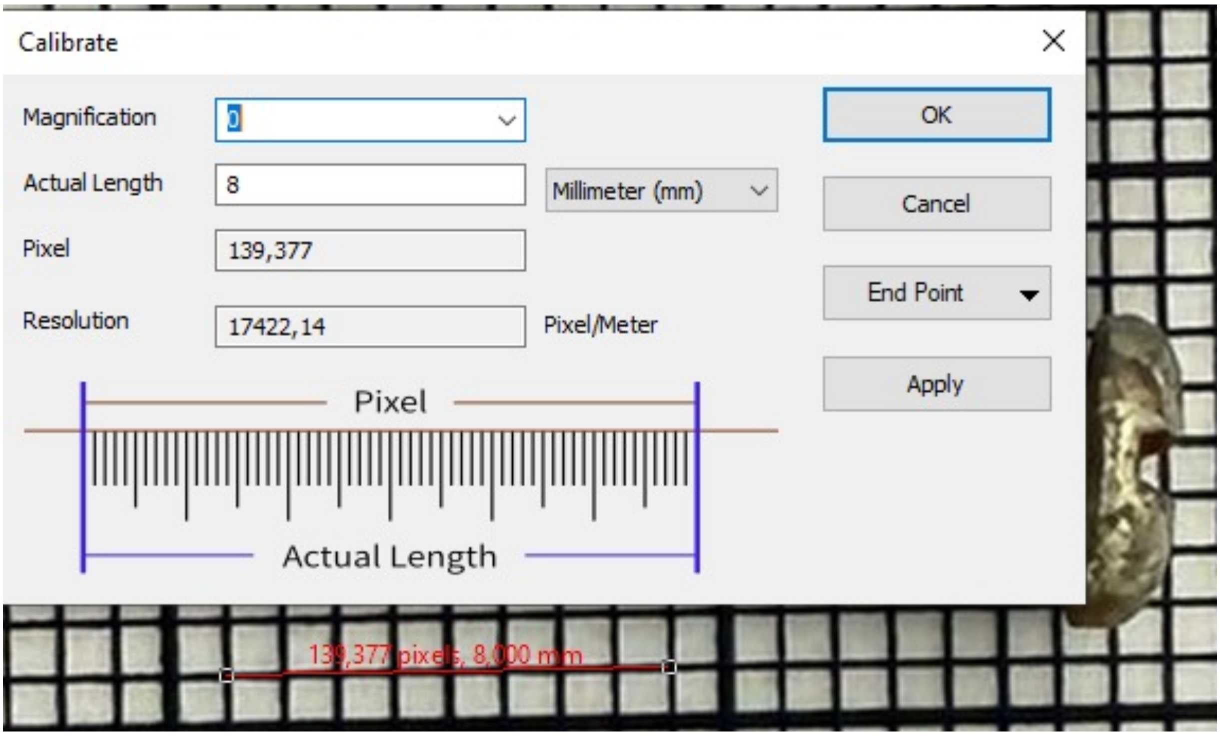

Figure 5.31 Calibration For ToupView Software

Screws Before (50 Speed)

Figure 5.32 Screws Before (50 Speed)

Screws After 15 Minutes (50 Speed)

Figure 5.33 Screws After 15 Minutes (50 Speed)

Screws After 30 Minutes (50 Speed)

Figure 5.34 Screws After 30 Minutes (50 Speed)

Screws After 45 Minutes (50 Speed)

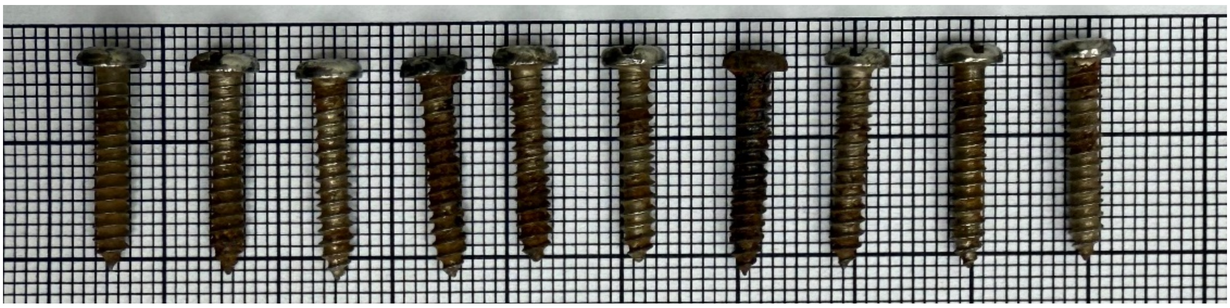

Figure 5.35 Screws After 45 Minutes (50 Speed)

Screws Before (70 Speed)

Figure 5.36 Screws Before (70 Speed)

Screws After 15 Minutes (70 Speed)

Figure 5.37 Screws After 15 Minutes (70 Speed)

Screws After 30 Minutes (70 Speed)

Figure 5.38 Screws After 30 Minutes (70 Speed)

After 45 Minutes (70 Speed)

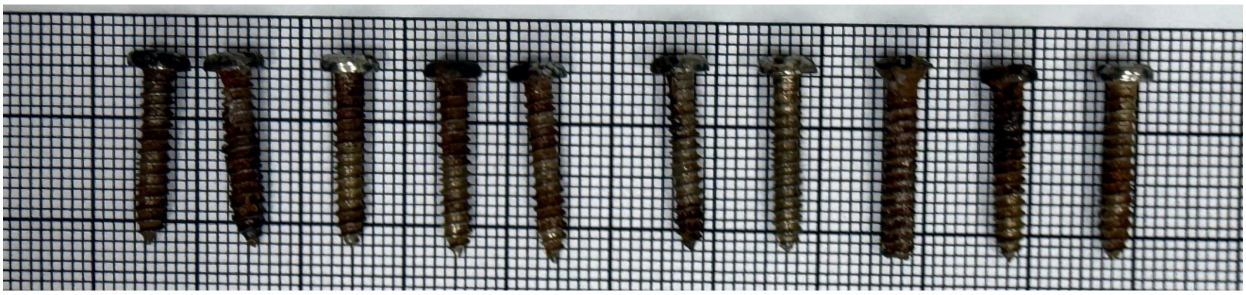

Figure 5.39 After 45 Minutes (70 Speed)

Screws Before (90 Speed)

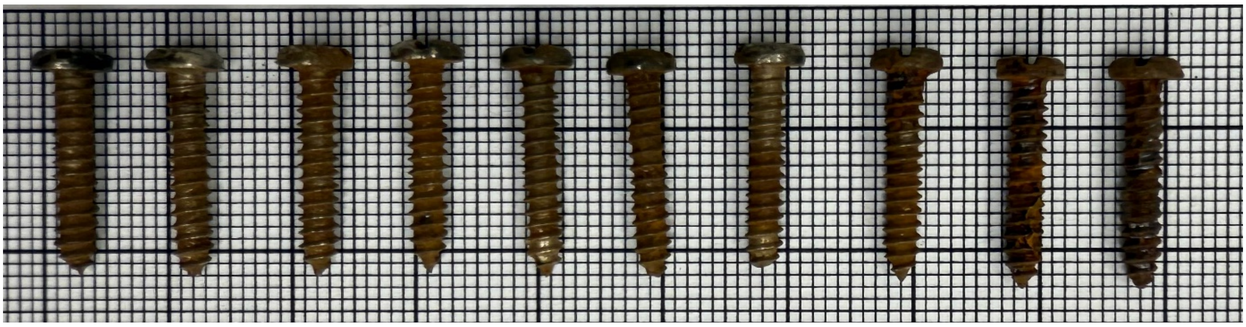

Figure 5.40 Screws Before (90 Speed)

Screws After 15 Minutes (90 Speed)

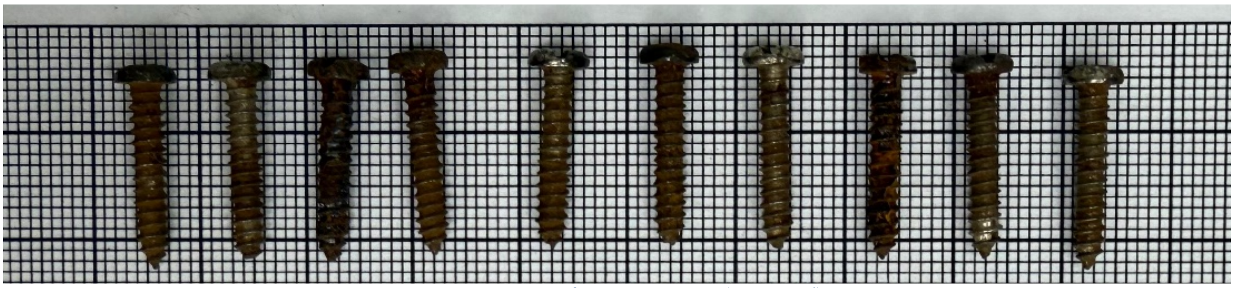

Figure 5.41 Screws After 15 Minutes (90 Speed)

Screws After 30 Minutes (90 Speed)

Figure 5.42 Screws After 30 Minutes (90 Speed)

After 45 Minutes (90 Speed)

Figure 5.43 After 45 Minutes (90 Speed)

Abrasive Debris and Corrosion Products

Figure 5.44 Abrasive Debris and Corrosion Products

6. CONCLUSION AND DISCUSSION

Abrasive tests were conducted on three different groups of ten screws using a rotary tumbler operating at three speed levels: 2790 rpm (50 speed), 3907 rpm (70 speed), and 5023 rpm (90 speed). Each group underwent three successive 15 minute tumbling sessions, with surface area measurements recorded at 15 minute intervals. The measurements were obtained using ToupView software via digital image analysis. To ensure data reliability, each screw was measured twice under identical conditions, and the mean value was calculated.

Surface area changes were monitored throughout the tests, and average values were tabulated for each screw group. The raw and averaged results are presented in tables. Figure 5.28 summarizes the mean surface area values for each speed setting as a function of time.

Surface Area Reduction at 50 Speed (2790 rpm)

The 50 speed configuration resulted in a steady yet moderate reduction of surface area throughout all samples. The surface area reduction reached about 2.74% after 45 minutes which demonstrated effective polishing at a moderate level. The setting maintained dimensional stability while it eliminated corrosion layers. The surface area curve shows a steady decline in smoothness because the abrasive media maintained continuous contact. The results in Table 5.7 and Figure 5.28 confirm the uniformity of material removal under this condition.

Surface Area Reduction at 70 Speed (3907 rpm)

The 70 speed condition produced the highest surface reduction among all tested configurations by removing about 5.66% of material during 45 minutes. The graph in Figure 35 displays the most pronounced downward slope for this group which indicates high kinetic energy and efficient motion transfer between ceramic media and screw surfaces. The selected speed maintains proper rotational force while maximizing particle-surface contact to become the most effective setting. Similar findings have been reported in the literature, where mid-range tumbling speeds resulted in optimal abrasion rates (Miller & Drozda, 2018).

Surface Area Reduction at 90 Speed (5023 rpm)

The 90 speed test achieved the fastest configuration yet it resulted in less surface reduction than the 70 speed test. The 45 minute test showed an average loss of 3.33% which was significantly lower than the mid-speed result. The ceramic media stuck to the tumbler walls because of excessive centrifugal force which reduced the direct impact between the screw surfaces. Similar phenomena have been documented in high-speed tumbling processes, where reduced relative motion lowers the efficiency of material removal.

Comparative Performance and Interpretation

The three speed settings demonstrate different abrasion behaviors through the data presented in Figure 37. The 70 speed condition produced the greatest surface reduction but the 50 speed setup preserved surface precision which made it suitable for parts needing minimal material removal. The 90 speed setting proved ineffective because it had reduced media-sample contact despite operating at the highest nominal rpm.

The findings show that maximum motor speed does not determine the best abrasive efficiency. The performance depends on the interaction dynamics between media and sample which are affected by tumbling velocity and geometry and centrifugal effects. The 70 speed configuration emerged as the best choice for aggressive yet controlled surface preparation.

7. REFERENCES

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8. APPENDICES

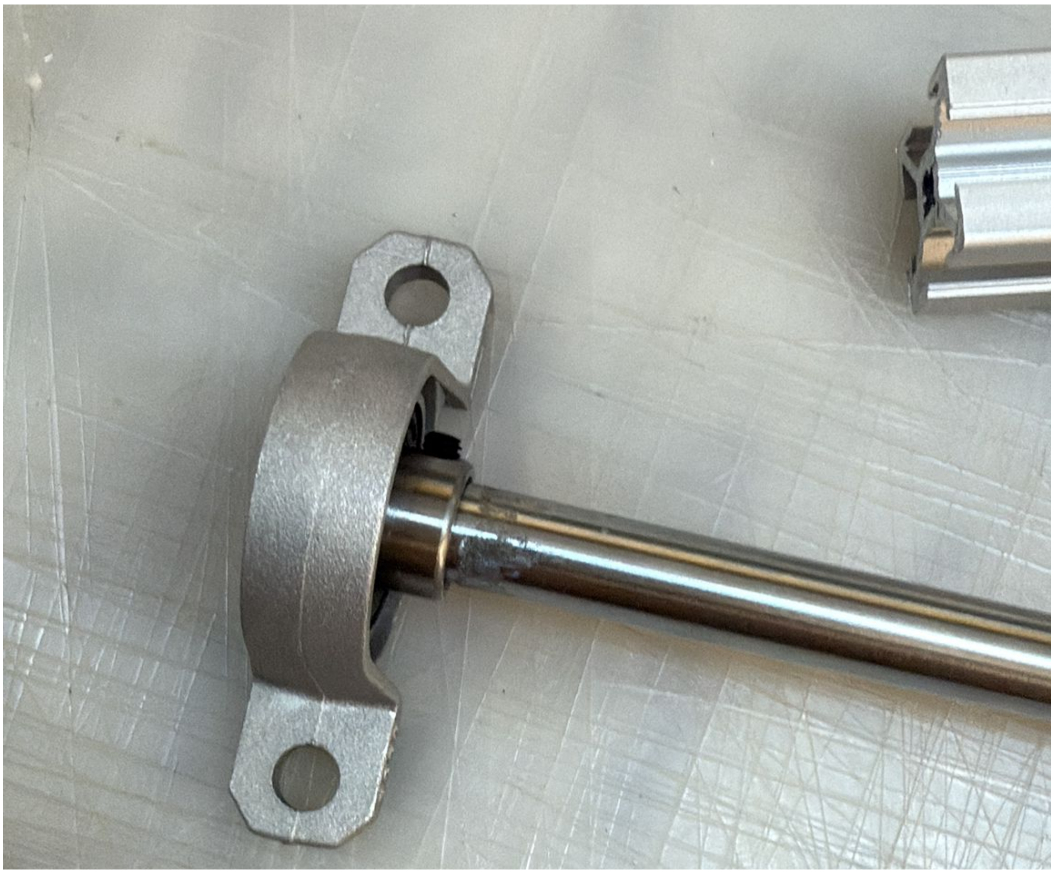

Figure 8.45 10mm Chrome Plated Induction Shaft Embedded In The Bearing

Figure 8.46 Chrome Plated Induction Shaft Embedded In The Bearing Both End

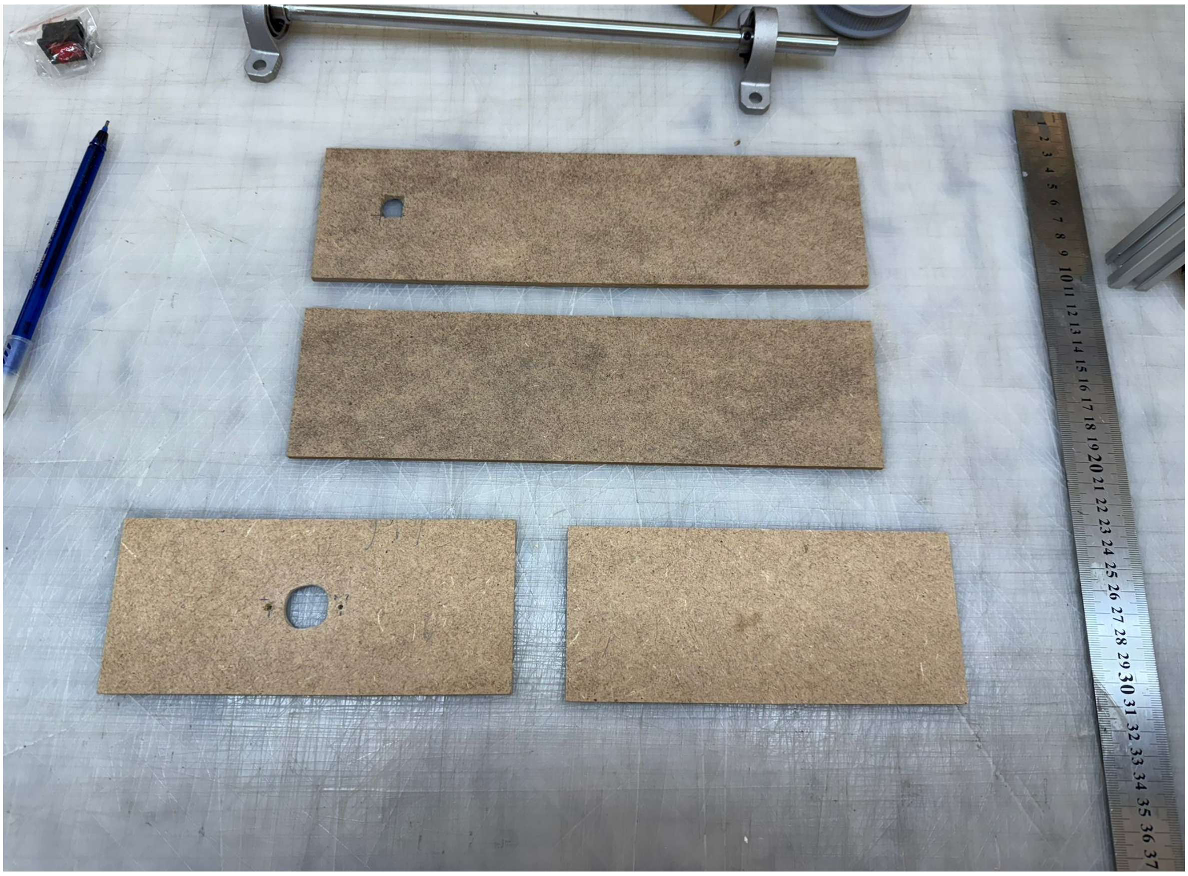

Figure 8.47 Side Covers Cut From MDF

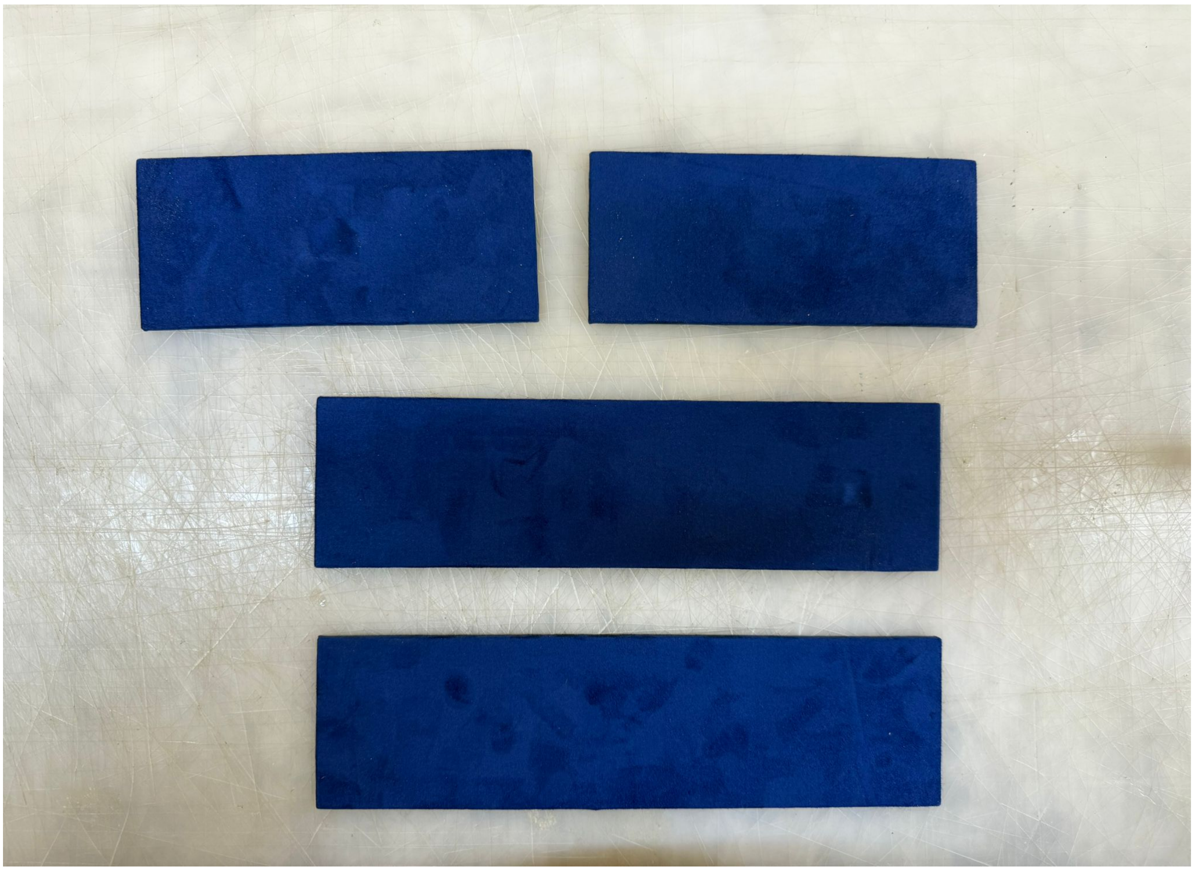

Figure 8.48 Coated MDF Covers

Figure 8.49 A Case Made With Aluminum Profiles.

Figure 8.50 Shafts and Bearings Mounted On An Aluminum Case

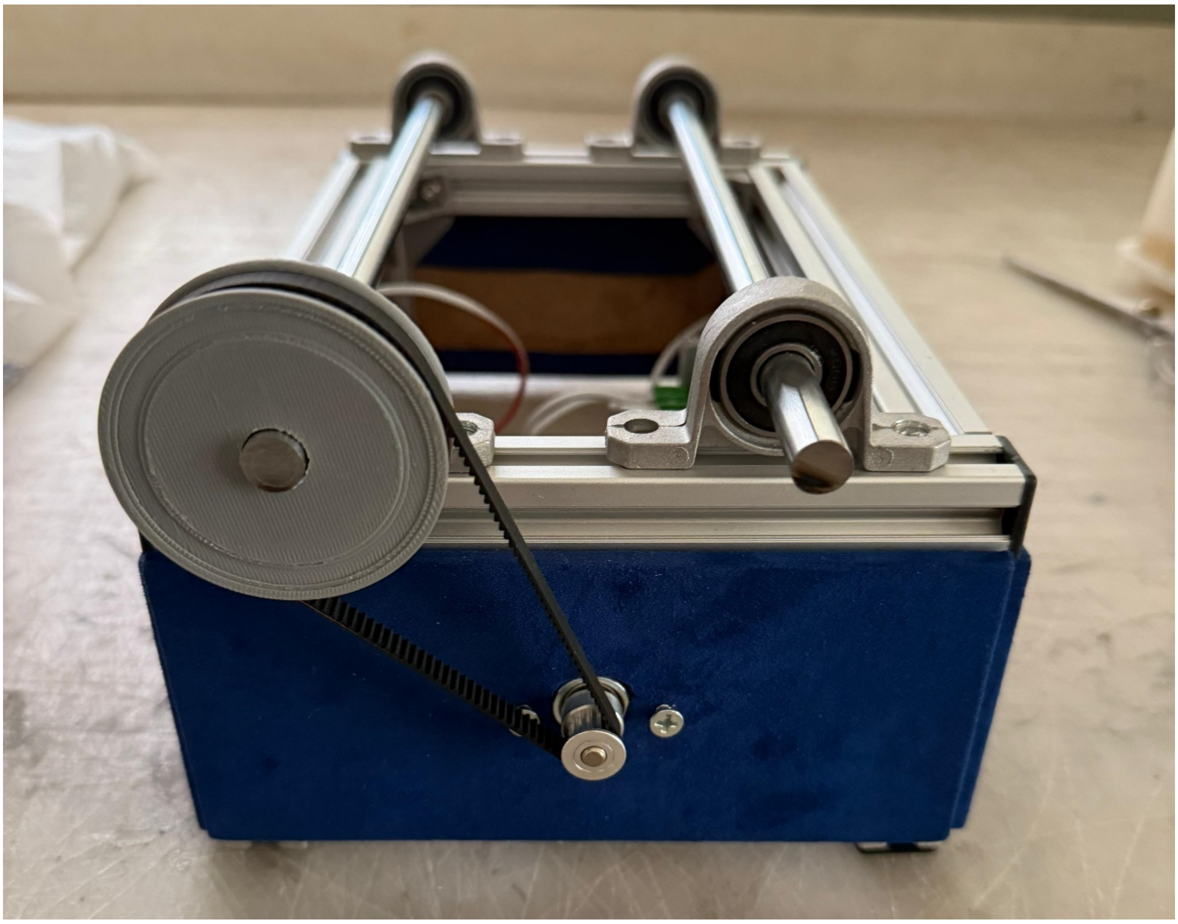

Figure 8.51 Gear-Belt System, Shafts and Bearings Mounted On An Aluminum Case That Covered With MDF Covers

Figure 8.52 Side View Gear-Belt System, Shafts and Bearings Mounted On An Aluminum Case That Covered With MDF Covers

Figure 8.53 Final Product

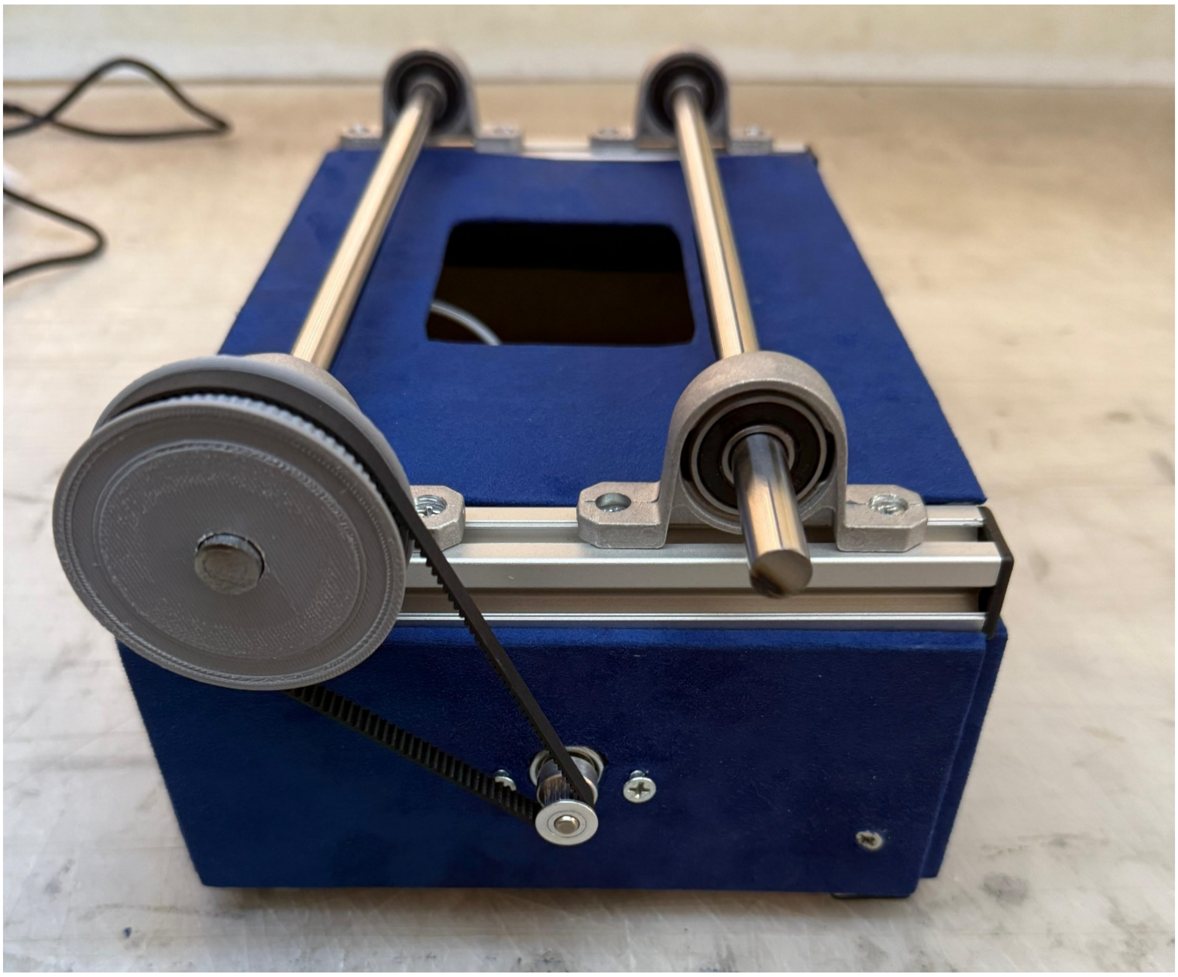

Figure 8.54 Final Product