GNG 1103

Design Project User and Product Manual

Rock ‘N’ Rode Accelerated Erosion Testing System

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List of Acronyms and Glossary

Table 1. Acronyms

Acronym	Definition
AETS	Accelerated Erosion Testing System
BOM	Bill of materials
CNL	Canadian Nuclear Laboratories
RNR	Rock ‘N’ Rode
RPM	Revolutions per Minute

Table 2. Glossary

Term	Acronym	Definition
Pulse Width Modulation	PWM	A dial that adjusts the speed of the motor
Highly Accelerated Lifetime Testing	HALT	Tests to assess the defects and weaknesses of the device

1 Introduction

This User and Product Manual (UPM) provides the information necessary for researchers to effectively use the accelerated erosion testing system (AETS) and for prototype documentation.

This document will cover: the purpose of this project, more specifically the problem statement identified from CNL; The final system and how it functions; Overview of the design process associated with this project; What could be done next after the termination of our working period on this project.

The document will go in-depth into how the wants and needs of CNL were processed and analyzed by Rock ‘n’ Rode (RNR). Specifically, the problem statement identified and how the course and overall goals of the project were decided. The document is intended for those interested in the designing process and the use of analytical models and ideas to create frameworks and a foundation for future physical models.

Please take note of the safety precautions in this manual if you plan to use this system. The proximity of electronics to liquid and the use of hard, solid abrasives can be dangerous if not treated cautiously.

Overview

Canadian Nuclear Laboratories need a cost-effective, reliable, no repeatable method for their material selection process. This is of importance because their previous procured parts were not as durable as they predicted. Being able to perform HALT on their procured parts, predicting its wear, and modelling it with high accuracy, is critical for their organization.

The users include laboratory technicians in CNL, material engineers and specialists, procurement and purchasing staff, maintenance staff, occupational health and safety personnel, and potentially geotechnical engineers. The needs of the client can be condensed into their need to find a procedure to follow for material selection. As such, they want to test their materials in an efficient, cost-effective manner, and with a certain degree of reliability.

What separates RNR from the usual accelerated erosion device team is the emphasis on theory and research. RNR understood that we couldn’t, or perhaps shouldn’t, focus our small budget and timeframe on attempting to create a hyper-functional device that could truly erode a million years’ worth of material in only a couple hours. Instead, we focused on identifying a relationship between a chosen independent variable and the wear rate (erosion, the dependent variable) so that a concept could be proven and said concept could be expanded on in the future. All RNR needed to do was prove a relationship of some sort and use extrapolation to effectively create a theoretical erosion accelerator.

Figure 1: Electronics Setup of the Device

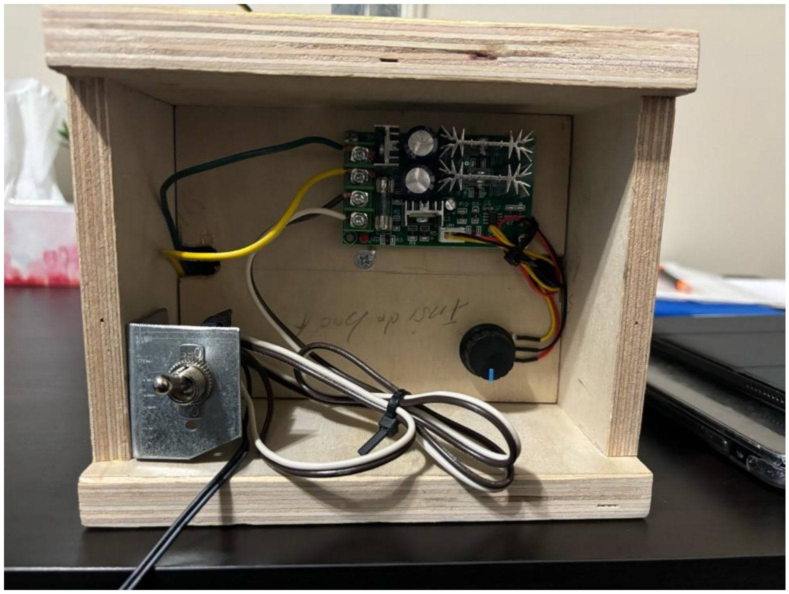


Figure 2: Top view of the Dismantled Device

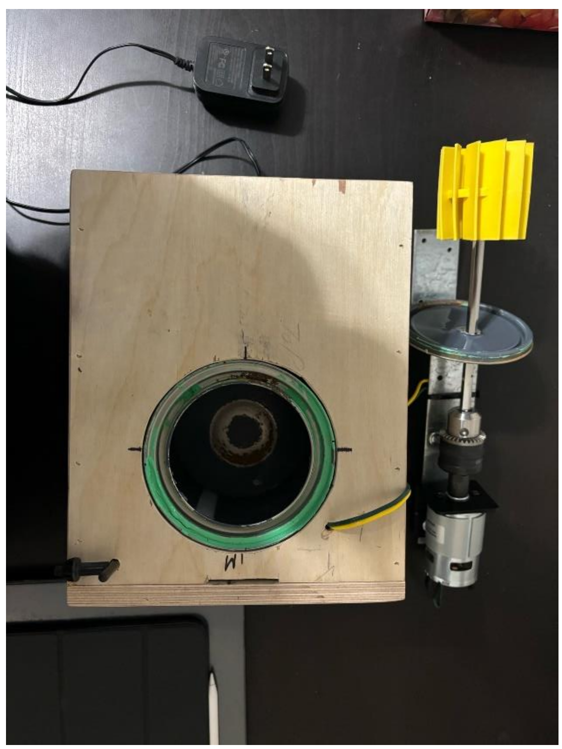


Figure 3: Side and Front View of the Assembled Device

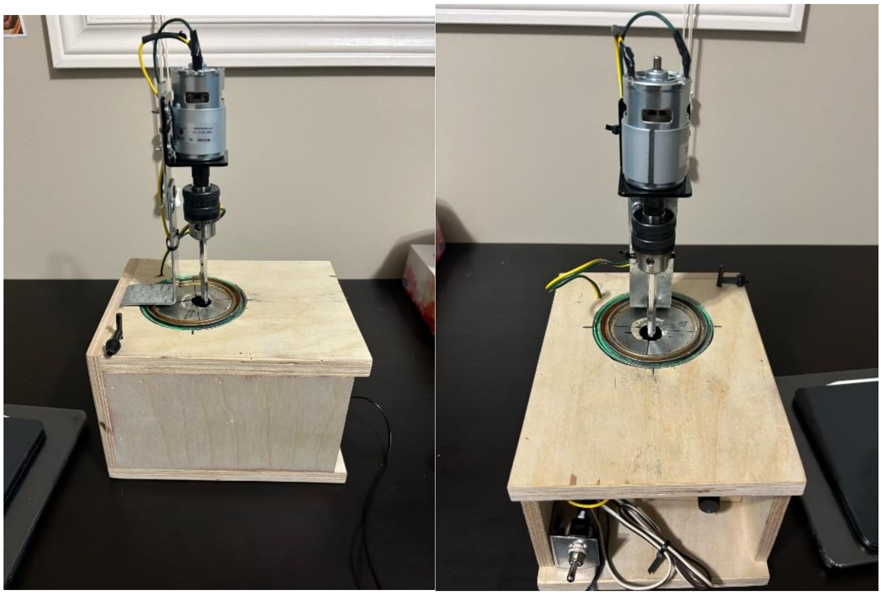
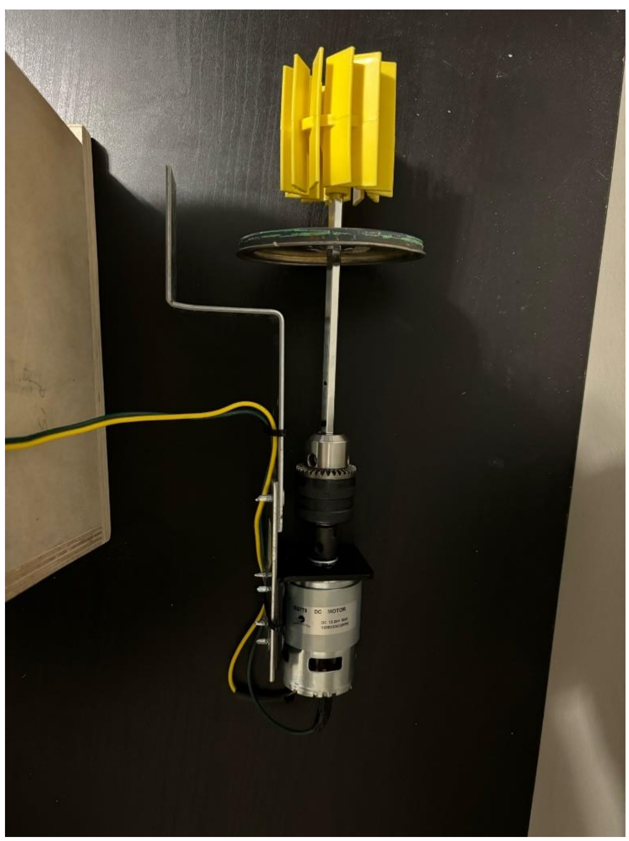


Figure 4: Impeller-Lid-Rod-Motor-Bracket Connection



Rock ‘N’ Rode’s AETS uses a PWM to control the speed of the motor (RPM) at any given moment. This allows for further control and agency in any tests taken. The motor spins the impeller that creates a slurry if an abrasive fluid is inside the container.

The system is held by a wooden frame, with the container subsystem being an aluminum can. The function is controlled by a PWM that varies the voltage supplied to the motor which is directly related to the RPM of the motor. A lever is also present, that when off, no voltage will be supplied at all.

Conventions

The lever used will be active when flipped up (the “off” setting) and will be “off” when flipped down (the “on” setting). This is due to the toggle switch’s polarity being flipped.

1.1 Cautions & Warnings

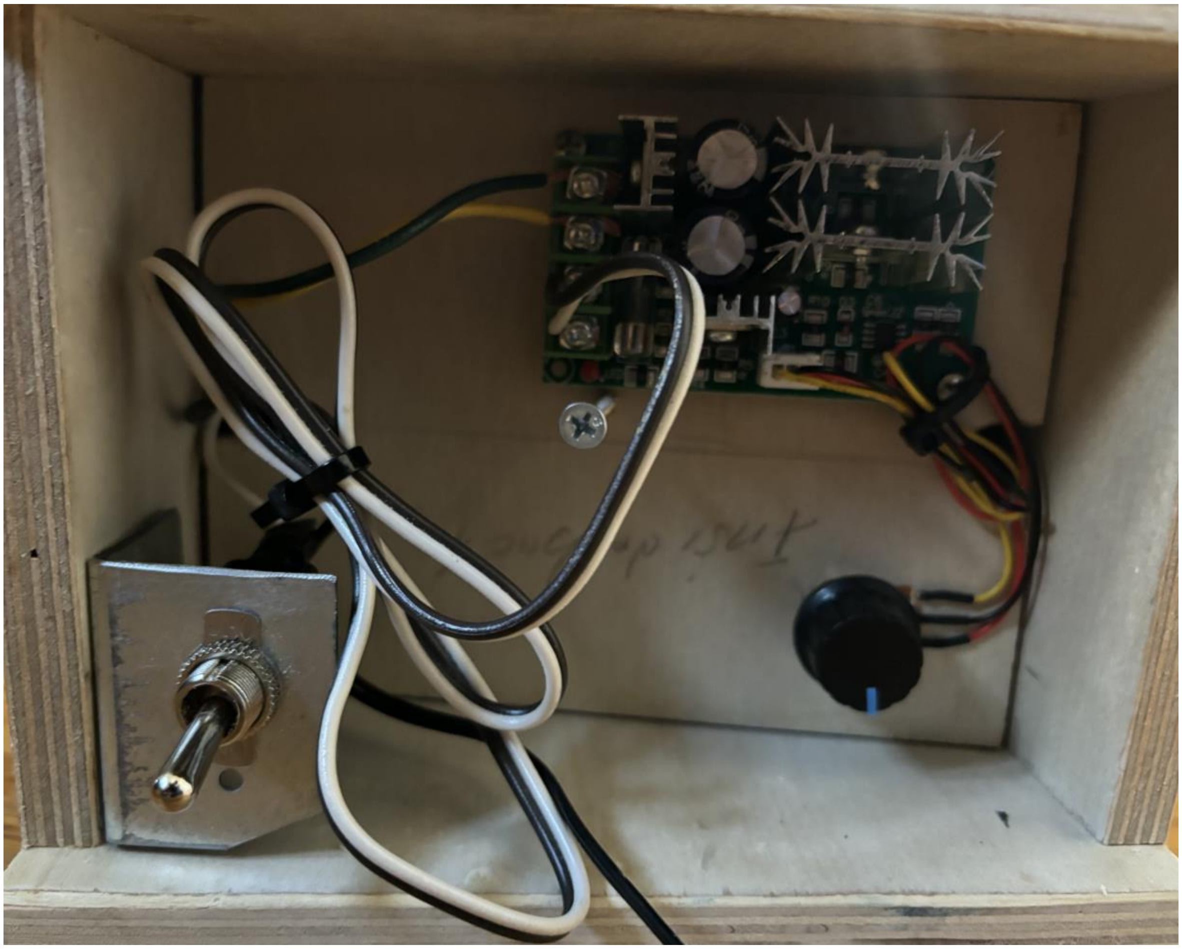
- The prototype uses aluminum oxide which is a fine abrasive. It is ranked 9 on the Mohs hardness scale providing a reasonable amount of danger if it were to splash out of the container. Make sure to properly seal the lid onto the container before initiating testing.
- The electronics are in relatively close proximity to water which could prove to be problematic/hazardous; make sure to properly seal the lid onto the container before initiating testing.

2 Getting started

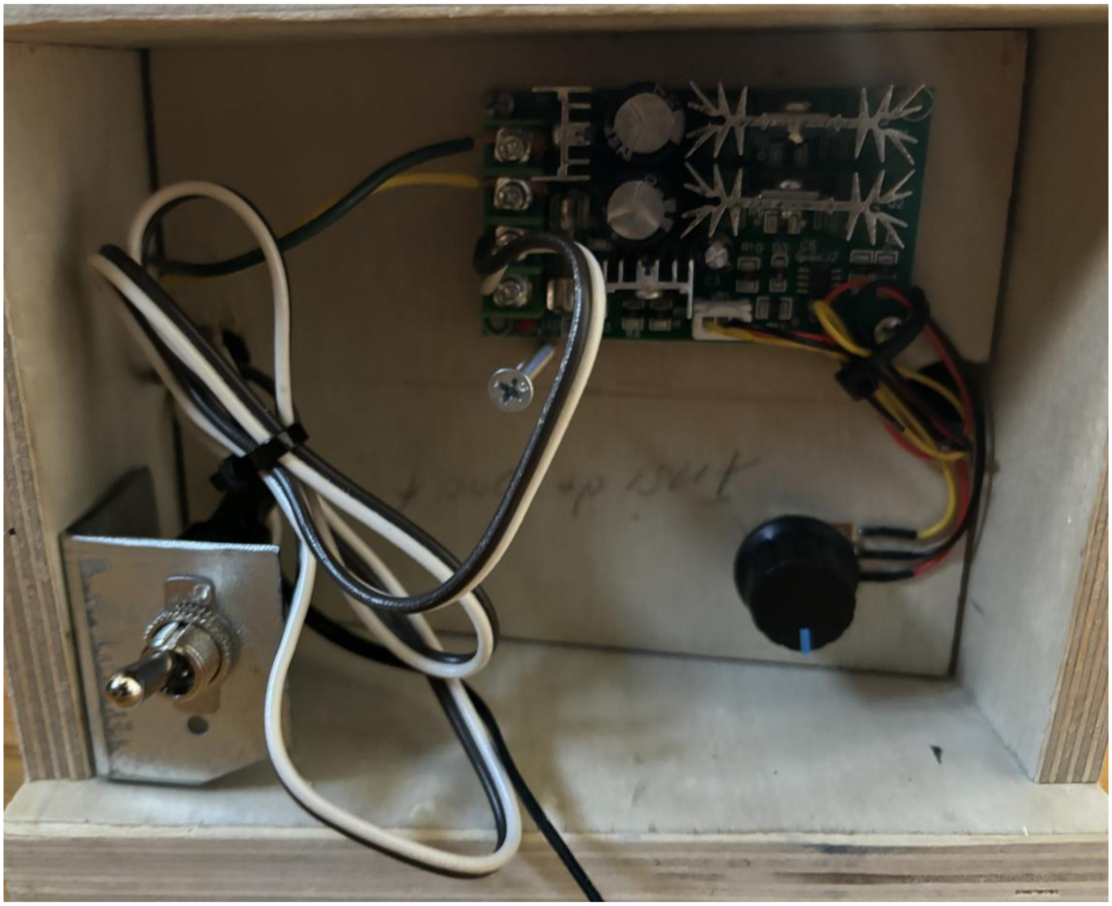
STEP 1 - To begin, the user should pour water and any amount of abrasive of the users' choice (RNR used aluminum oxide).

STEP 2 - The user will have to insert the plug into any outlet in range (extension cords may have to be used depending on where it’ll be positioned).

STEP 3 – After making sure that there are no wires obstructing the motor or the impeller and that no liquid has been dropped on the electronics, the speed controller knob should be turned completely off (all the way counter-clockwise).



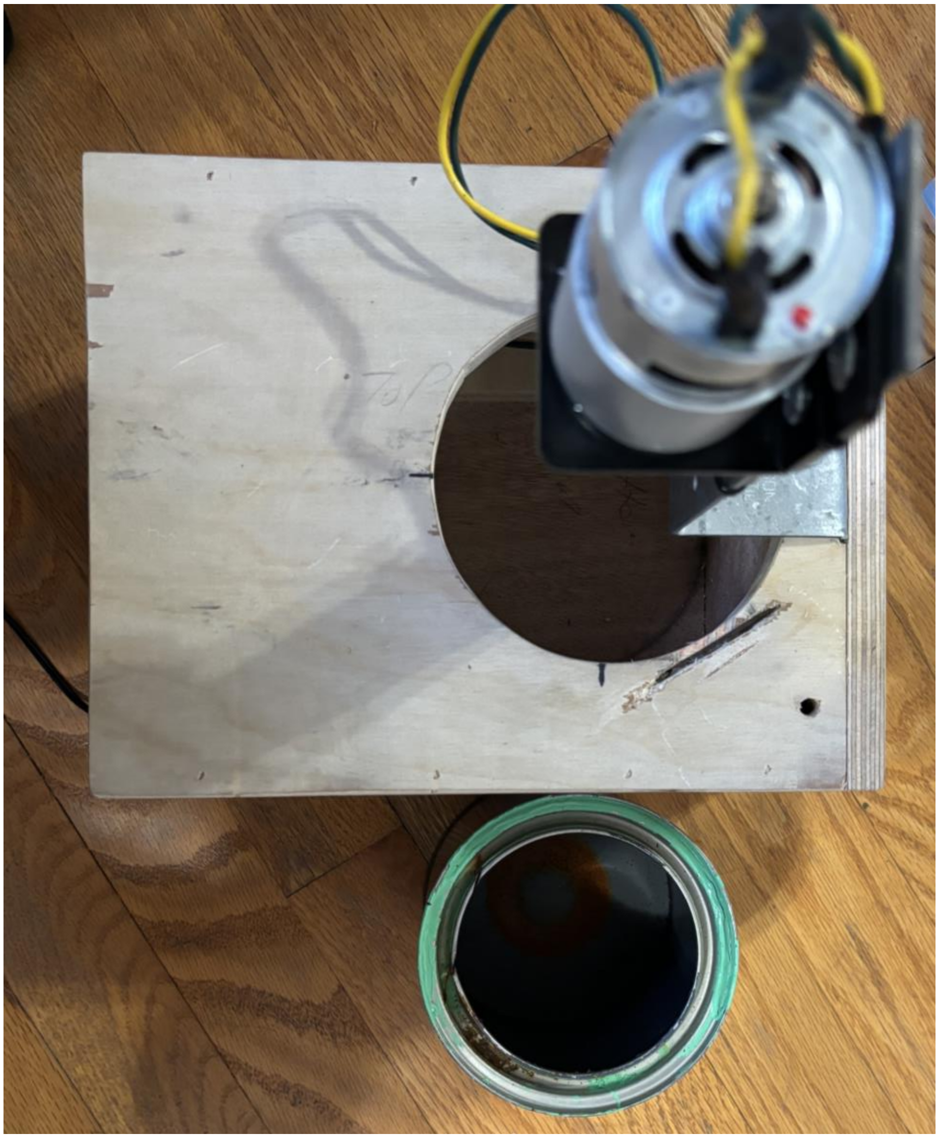
STEP 4 – The toggle switch can then be toggled ON which can be viewed from the lettering on the switch. Another indicator is to flick the switch up to turn it ON.



STEP 5 – Lastly, the speed controller knob can be slowly turned clockwise until the desired RPM has been reached.

STEP 6 – The motor can now be turned off 1 of 3 ways: Unplugging the power source, reducing the speed of the speed controller until completely off, turning the toggle switch OFF.

STEP 7 – Disposing of the slurry can be done by removing the container by sliding it out and pouring it in a hazardous waste container (if using aluminum oxide). If using an organic waste, this can be disposed in approved areas.



- DO NOT DRAIN ALUMINUM OXIDE OR ANY ABRASIVES THAT CAN BE HARMFUL INTO PLUMBNING SYSTEMS!

Configuration Considerations

To configure the AETS, ensure first that the system is plugged into an outlet with at least 10 volts being supplied if maximum power is desired. However, since the PWM works proportionally, as long as some sort of power is supplied, the AETS will work. Make sure the AETS has space around it, as it can vibrate quite harshly at times and may risk damaging things around it. Fortunately, every connection is included inside the system, so all that is needed from the user's end is plugging it in, filling the container with water and a select amount of abrasive, turning on the lever, and setting the PWM to whatever intensity wanted.

2.1 User Access Considerations

Researchers

We will define a researcher as a user with professional or extensive educational experience in conducting scientific research of some sort. Ideally a user with lab experience.

If a researcher of some sort were to use this AETS, they would be permitted to change the amount of abrasive in the container subsystem and conduct full-scale tests if they so wish, provided they are familiar with the operation and safety precautions needed.

Students

We will define a student as a user with little to no professional experience in conducting scientific research and some educational experience. Ideally, the user has some lab experience.

If a student were to use this AETS, they would not be permitted to run full scale/duration tests nor using abrasives. They would be allowed to run the system with no abrasives inside the container, however water can be present. However, they must be familiar with the operation of the AETS and the safety precautions needed. Furthermore, the supervision of either a member of RNR or a researcher approved by RNR.

2.2 Accessing/setting up the System + Use

1. Safely dispose of any liquid-abrasive mixture in the container before starting.
2. Ensure all wires are in place and not close to the container's interior. Ensure the lever is off and no power is flowing.
3. Fill container with 250 mL (This is roughly a third of the container's volume. Users designated by RNR can vary this volume if they wish) of water.
4. Insert any sample into sample holder (optional). Before doing this, feel free to measure either the mass or volume of the sample.
5. Add abrasive (aluminum oxide was used by RNR) to the water. Since this is your independent variable, this can be varied however chosen.
6. Securely close the lid of the container.

<u>From step 7 onwards comes the testing portion rather than the accessing portion.</u>

7. Set the PWM to whatever power you wish. This will determine your RPM.
8. Turn on lever to allow power to flow.
9. Optionally, the sample can be added in this step to avoid the acceleration part eroding the sample. However, it is quite negligible.
10. Allow the AETS to function for as long as you wish. Make sure to note your test duration.

11. When the test duration has finished, turn off the lever and dial down the PWM.
12. Open the lid and remove the sample. Measure either the new mass or volume to calculate your wear rate.

2.2 2.3 System Organization & Navigation

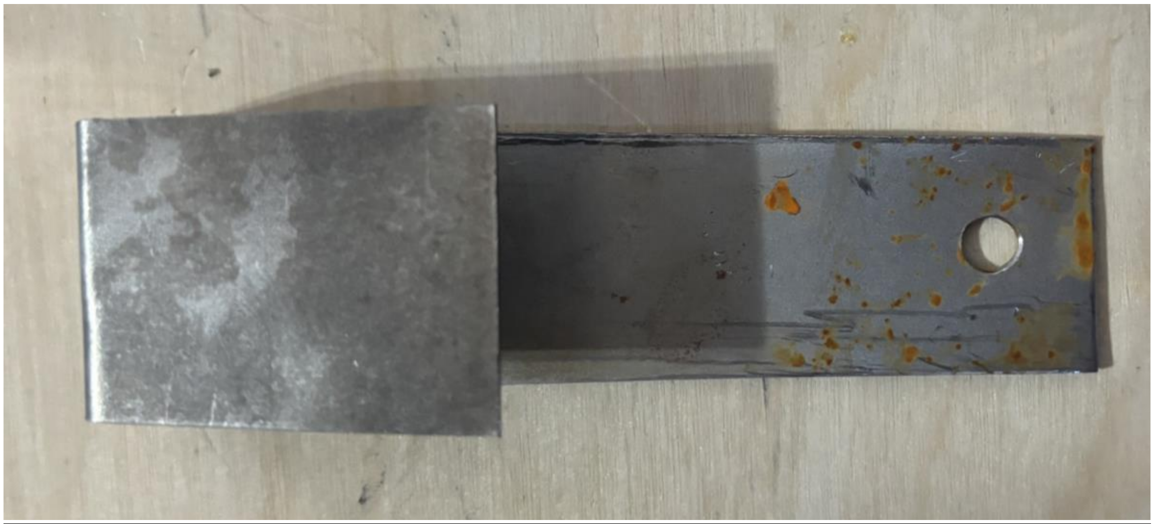
Lever

The lever is used to allow power to pass through the system. Keep this off when the system isn't in use and only on when the system is testing.

PWM

The PWM varies the power supplied to the system and will subsequently alter the rpm. Set this PWM to the desired RPM before turning on the lever.

Sample Holder



The sample holder is a removable piece of sheet metal that slides into the container and can hold a sample. It can either be placed into the container before the motor spins or after, with the former letting the accelerating period affect it.

2.4 Exiting the System

To ensure sufficient safety, turn off the PWM first. Then, proceed to turn off the power (turn switch off) and unplug the device. If you would like to minimize the deceleration, though, first turn off the lever and ENSURE the PWM is turned off afterwards. Once these conditions are fulfilled, open the lid and remove the sample holder and retrieve your sample. Safely empty the fluid abrasive (not down a drain). Securely close the lid and put the device away.

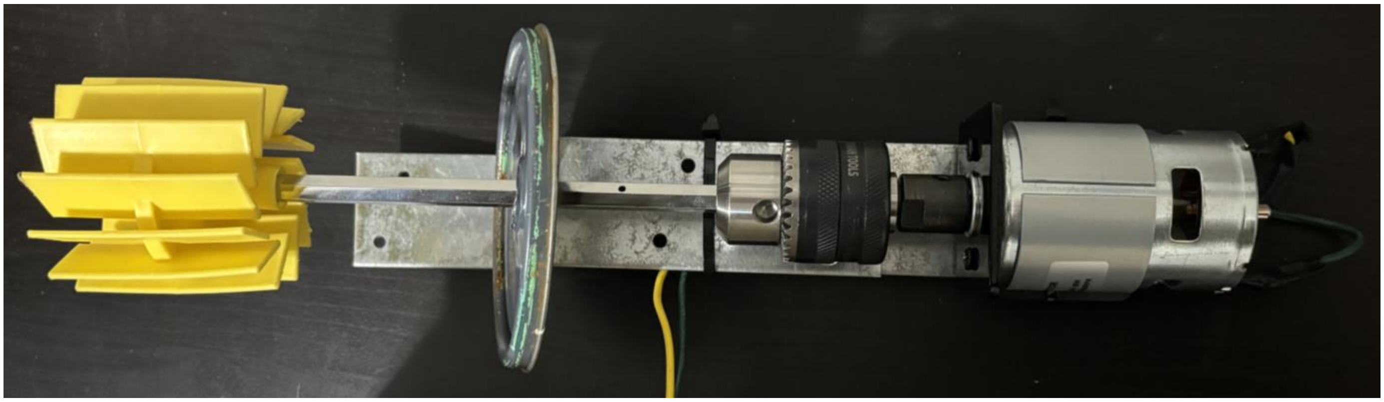
Using the System

Refer to 2.2 to see the proper procedure in using the AETS.

The following sub-sections provide detailed, step-by-step instructions on how to use the various functions or features of the AETS.

<Motor/Power and Spinning>

The motor subsystem is what is used to power the system and the overall functionality. It is what causes the slurry, spinning the rod/impeller to create the eroding environment. For the user's concern, there are some sub systems associated with the motor that need to be mastered.



<Lever/On & Off>

The lever is used to allow power to pass through the system and to the motor. Keep this off when the system isn't in use and only on when the system is testing. Power is not running when the lever points up and power is running when the lever points down.

<PWM/RPM>

The PWM varies the power supplied to the motor and will subsequently alter the rpm. Set this PWM to the desired RPM before turning on the lever. Make sure to turn it off when done with the system so the motor doesn't spin unexpectedly when it is next turned on.

<Aluminum Can/Container>

The aluminum can is used to contain the sample and the slurry. It is important that it is well maintained and set up. For the user's sake, the important thing is knowing that it has a lid that needs to be attached when conducting tests, and that it can be removed to adjust the slurry.

<Metal Bracket/Sample Holder>

The sample holder is a removable piece of sheet metal that slides into the container and can hold a sample. It can either be placed into the container before the motor spins or after, with the former letting the accelerating period affect it.

4 Troubleshooting & Support

4.1 Error Messages or Behaviors

There are no error messages associated with our AETS; however, some parts may show signs or behaviors of damage. If the RPM seems to be varying a lot when it is meant to be constant, the motor, circuit, or PWM might be damaged. If this is the case, please refer to the Support subheading.

4.2 Maintenance

Regular cleaning of the container should be performed to guarantee consistent results. This should be performed after every completed trial. Removing the electronics and performing inspections inside and around the system should be done before and after every trial to spot any potential failures. Lastly, removing the chuck assembly along with the rod to clean the internal components should be done when the user sees fit. This means that whenever there's a visual amount of debris accumulated onto it.

4.3 Support

Please contact any of the RNR members if support is needed:

Ahmed Qadori – aqado096@uottawa.ca

Kayhan Javad – kjava047@uottawa.ca

Robert Gauvreau – rgauv085@uottawa.ca

Tyler Ash – tash065@uottawa.ca

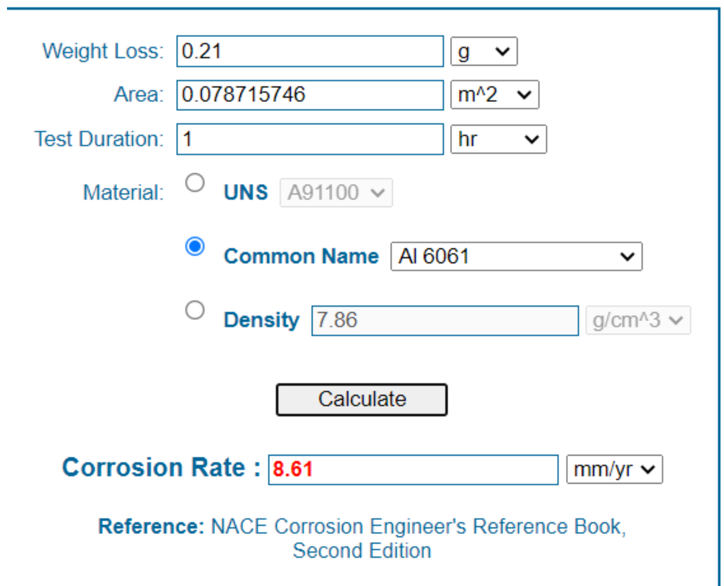
When reporting, send an email to any of the above emails with the subject line "AETS SUPPORT".

5 Product Documentation and Instructions

Prototype III solidified the capabilities of our final prototype. The motor was required to produce +2000 RPM, where it was capable of producing +5000 RPM, which could be varied using a scaled PWM. We found that dialing the PWM 90 degrees was sufficient to produce the necessary power to erode materials, whereas beyond that is unnecessarily strong for wear and would produce unrealistic results. We were able to change other parameters with ease such as concentration of aluminum oxide, temperature of water using a kettle, time, and surface area of water.

Using iterations on a span of 4 hours (to ensure the motor would not overheat), we tested the walls of the aluminum container first and used 0.01+/- precision accuracy to measure the weight lost. The container was emptied and dried, and was subsequently weighed. Furthermore, the real value of the wear rate was measured using the MESTEEL calculator, which reference the NACE Corrosion Engineer's Reference Book, Second Edition, as shown in figure 5.

Figure 5 MESTEEL Calculator (MESTEEL, 2024)



Subsystem 1: Electrical

The electrical subsystem was conceptualized in Prototype II as shown in figure 6 and its code in figure 7

Figure 6 Electrical wiring (Prototype II)

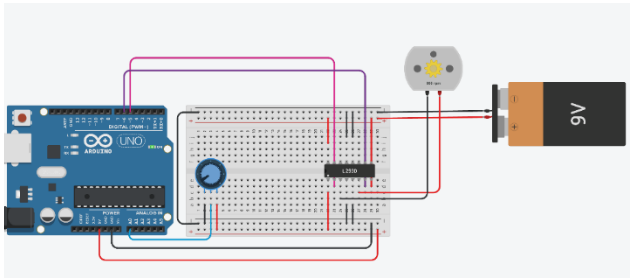


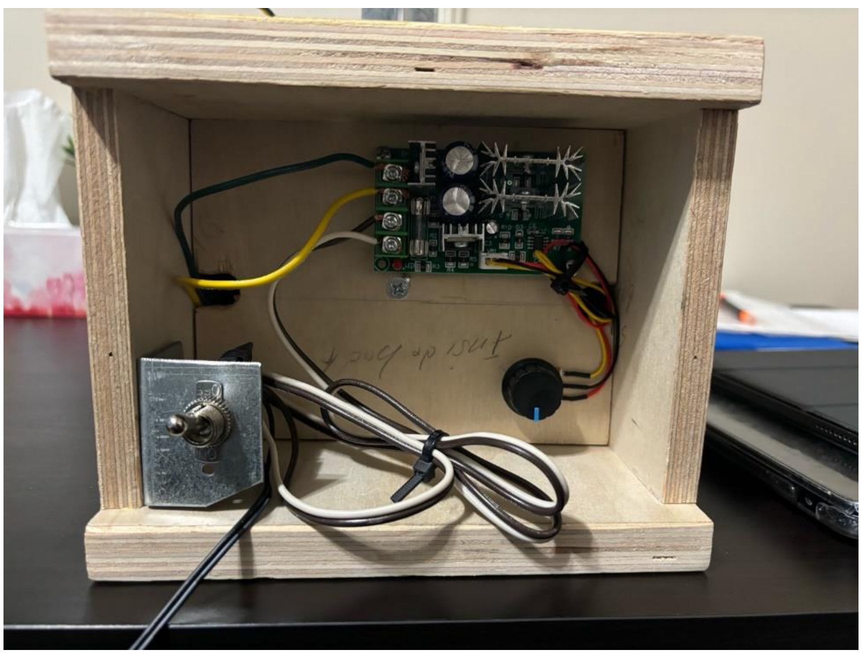
Figure 7 Arduino Motor code

```cpp
// C++ code

int potIn;
int fwdPin = 5;
int revPin = 6;


void setup()
{
  pinMode (fwdPin, OUTPUT);
  pinMode (revPin, OUTPUT);

 Serial.begin(9600);
}

void loop()
{
 potIn = analogRead(A0);
  int output = potIn/4;

  analogWrite (revPin, output);

  Serial.println(output);
  delay(100);
}
```

It was later scrapped with the use of a PWM to adjust the speed to minimize external wiring and maximize the product's aesthetic minimalism as show in figure X. An external electronic power output device such as a laptop is no longer necessary as the power can be connected easily from an outlet.

Material	Cost to Replicate in CAD ($) (Inclusive of HST)	Cost for us to Produce in CAD ($) (Inclusive of HST)	Link to the Item
Mini Electric Motor 12V//24V (Part of bundle)	30.00 (Estimate)	18.07	https://www.amazon.ca/dp/B08H88TYCN?ref=ppx_yo2ov_dt_b_product_details&th=1
PWM DC Motor Speed Controller (Part of bundle)	8.00 (Estimate)	0.00	https://www.amazon.ca/dp/B08H88TYCN?ref=ppx_yo2ov_dt_b_product_details&th=1

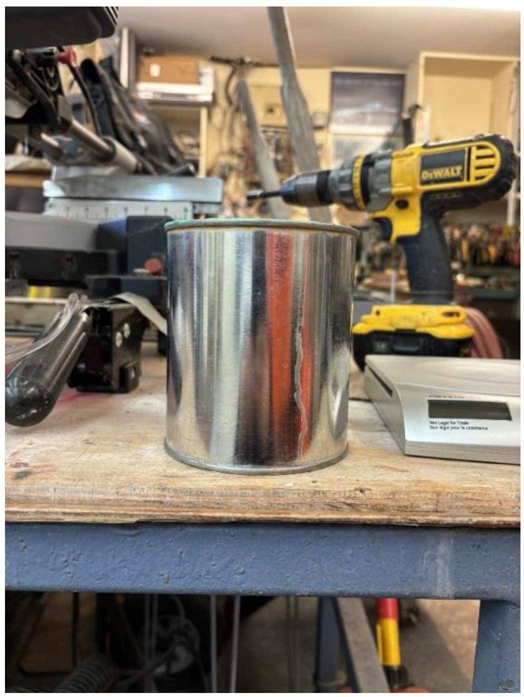
Figure 8 Non-external wiring setup



Subsystem 2: Mechanical

Since its conception, the aluminum can, as shown in figure 9, remained consistently durable throughout all stages of testing and prototyping. It even served as the placebo testing iteration. It was the balance needed between durability and minimum wear needed to extrapolate. Along with the rod and impeller, as shown in figure 10, the durability of these materials are able to withstand extreme conditions for a limited amount of time, deeming them fit for prototyping.

Figure 9 Aluminum Can



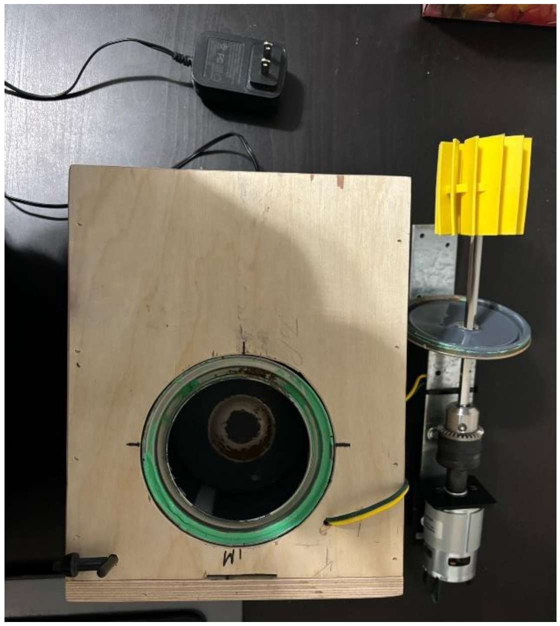
Moreover, to ensure the flexibility of the device to install new rods, parts, or general adjustments to the setup, a chuck was added, which facilitated the rod-motor-impeller connection, fixed by an L-bracket on to the container as shown in figure 10

Material	Cost to Replicate in CAD ($) (Inclusive of HST)	Cost for us to Produce in CAD ($) (Inclusive of HST)	Link to the Item
Epoxy Resin	0.50	0.00	
Metal Washer	0.25	0.00	
18 Volt Battery	21.25	0.00	
Copper Wire and Clamp	2.00	0.00	
Paint Can (1 Quart)	6.00	0.00	

Subsystem 3: Container

As the name implies, a container system needs to contain the mechanical and electrical wiring. It would be unprofessional, unsafe, and disorganized to connect the mechanical and electrical systems in a manner that would expose the PWM, motor, and the wiring next to a 5000+ RPM mixer with fluids and abrasives. As such, a compartmentalized wooden container was utilized to hold the samples as shown in figure 10

Figure 10 Subsystems compartmentalized in the wooden container



Material	Cost to Replicate in CAD ($) (Inclusive of HST)	Cost for us to Produce in CAD ($) (Inclusive of HST)	Link to the Item
Plywood	5.00	0.00	
Metal Angle	2.00	0.00	

Complete BOM (Bill of Materials)

Material	Cost to Replicate in CAD ($) (Inclusive of HST)	Cost for us to Produce in CAD ($) (Inclusive of HST)	Link to the Item
Mini Electric Motor 12V//24V	48.48	48.48	https://www.amazon.ca/dp/B08H88TYCN?ref=ppx_yo2ov_dt_b_product_details&th=1
Drill Chuck			

PWM DC Motor Speed Controller			
Aluminum Oxide	18.07	18.07	https://www.canadiantire.ca/en/pdp/mastercraft-general-purpose-sandblasting-media-with-medium-aluminum-oxide-40-60-grit-0589447p.0589447.html
Plywood	5.00	0.00	
Metal Stabilizers	3.00	0.00	
Paint Can (1 Quart)	6.00	0.00	
Metal Angle	2.00	0.00	
18 Volt Battery	21.25	0.00	
Copper Wire and Clamp	2.00	0.00	
Epoxy Resin	0.50	0.00	
Metal Washer	0.25	0.00	

Shown above is the BOM for our final prototype. For each material there are two columns, one showing the price it would cost for someone else to replicate our design and one showing the price it cost us build our design. Some items are shown as $0 items as we were able to salvage them or find/use them for free.

Equipment list

Below is a list of equipment that was used while building this subsystem for our AETS:

Equipment/Tool	Accessibility
Virtual Chemistry Lab	Via University Access
Google Drawing	Free
(CAD) On Shape	Free
High-Precision Digital Scale	Geotechnical Lab, CBY
Microsoft Excel	Free

MESTEEL Calculator	Free
TinkerCAD	Free

Testing & Validation

All test iterations featured in figures 11-13 clearly illustrate the trend summarized in figure 14. The concentration of the abrasive was varied while performing tests for a duration of 1 hour under fixed conditions such as boiling water temperature, the same surface area of the filled paint can, and it was assume factors such as pressure are not interfering in the erosion process. Whereas the real value was taken from the MESTEEL calculator. The weight loss of the can was measured using a highly precise electric scale in the Geotech lab in CBY. Subsequently, Gupta et al.'s 1995 equation was used to find our predicted wear rate in mm/year.

$$Wear\ rate\ in\ \frac{mm}{year} = \frac{W_L}{S \times Surface\ area} \times \frac{8760}{T} \times 10^3$$

W_L = measured weight loss (kg)

S= Relative density of material (kg/m^3)

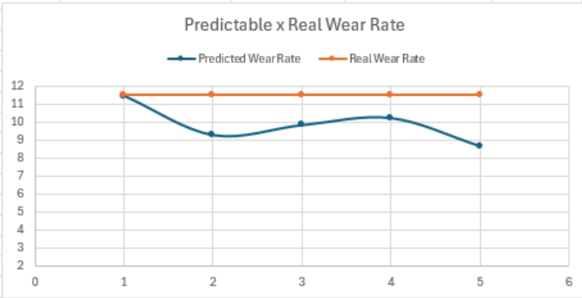
T= Duration of test (h)

Figure 11 Test Iteration I: 100g Abrasive

Date 2024-04-02

	Surface Area	0.078715746
RPM= 2500	Abrasive Concentration=	100g
Temp= 102 *C	Time (h)=	1

Iteration X	Weight lost (g	Predicted wear rate	Real Value	Relative True Error	Desired RTE (<15%)	Relative Approx. Error
Iteration 1	0.28	11.43507529	11.48	0.39133%	15%	
Iteration 2	0.22	9.261510029	11.48	19.32483%	15%	19%
Iteration 3	0.24	9.817200631	11.48	14.48432%	15%	6%
Iteration 4	0.25	10.20988866	11.48	11.06369%	15%	4%
Iteration 5	0.21	8.65561685	11.48	24.60264%	15%	15%
Avg	0.24	9.875858292	11.48	13.97336%		11.05777%
			Avg	13.97336%		



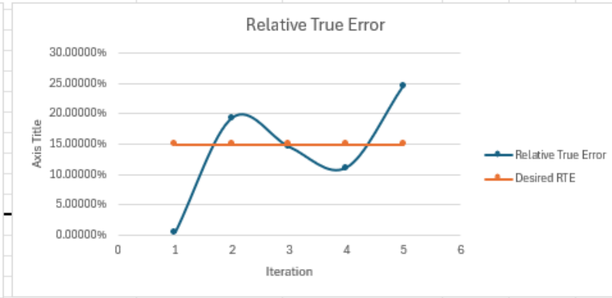


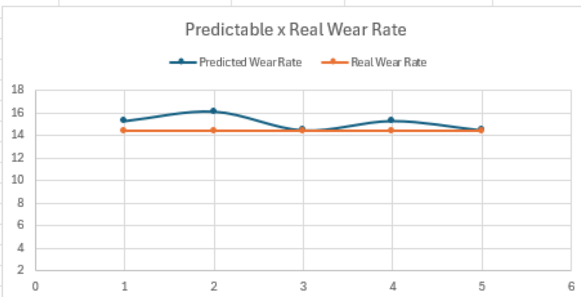
Figure 12 Test Iteration II: 300g Abrasive

Date 2024-04-03

	Surface Area	0.078715746
RPM= 2500	Abrasive Concentration=	300g
Temp= 102 °C	Time (h)=	1

Iteration X	Weight lost (g	Predicted wear rate	Real Value	Relative True Error	Desired RTE (<15%)	Relative Approx. Error
Iteration 1	0.37	15.25037254	14.36	6.20037%	15%	
Iteration 2	0.39	16.07471701	14.36	11.94093%	15%	5%
Iteration 3	0.35	14.42602808	14.36	0.45981%	15%	10%
Iteration 4	0.37	15.25037254	14.36	6.20037%	15%	6%
Iteration 5	0.35	14.42602808	14.36	0.45981%	15%	5%
Avg	0.37	15.08550365	14.36	5.05225%		6.69538%
			Avg	5.05225%		

sS



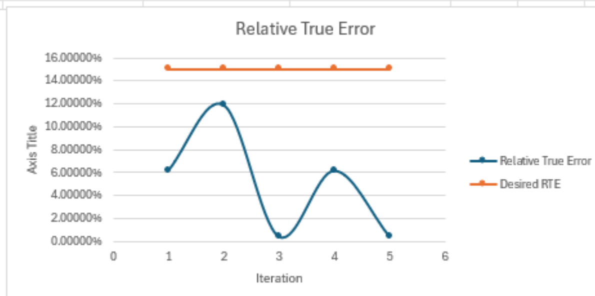
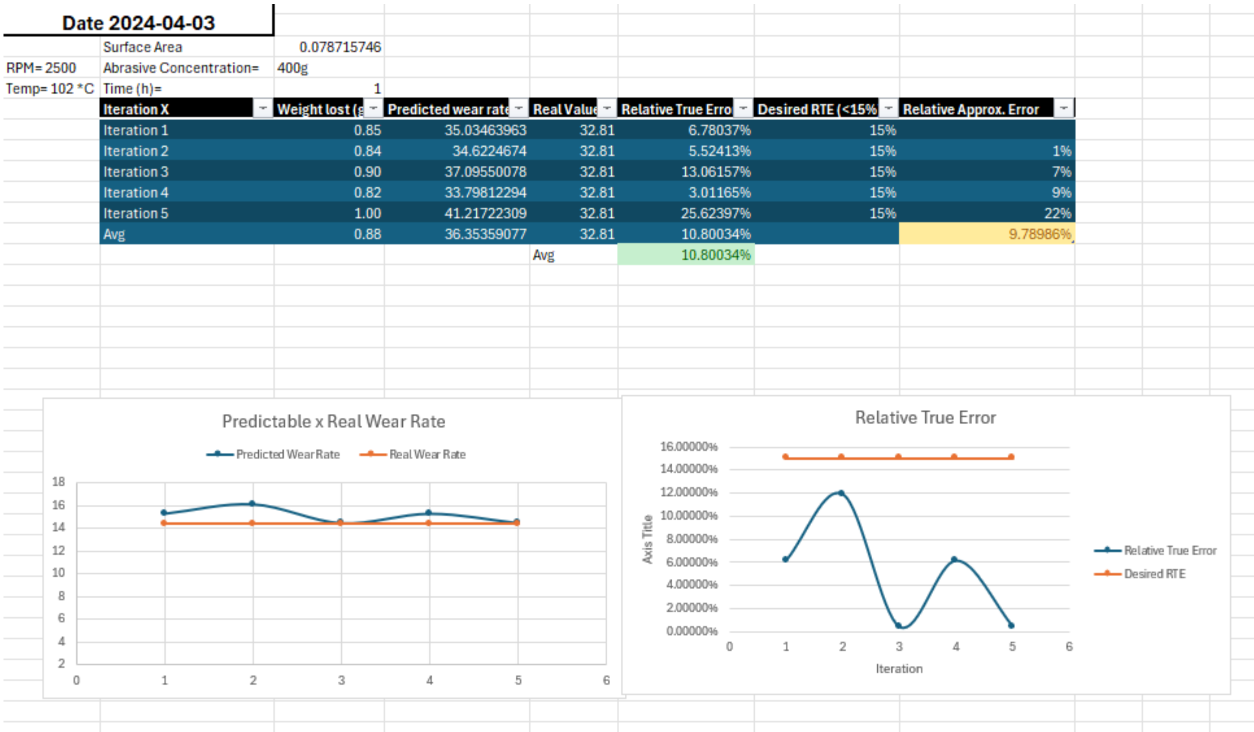
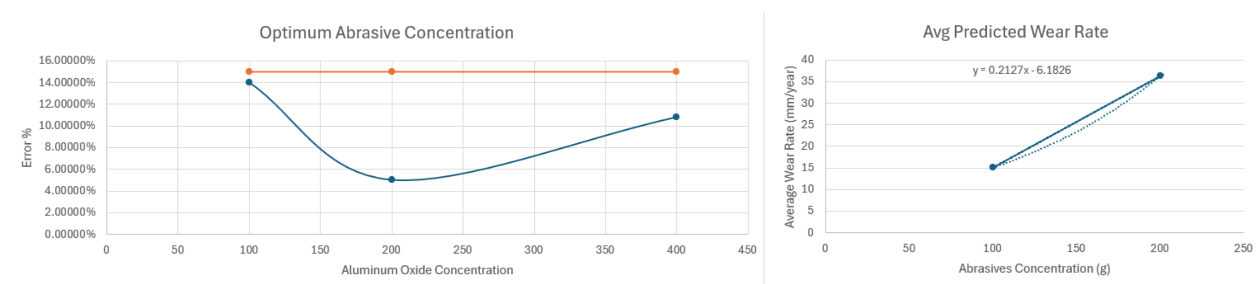


Figure 13 Test Iteration III: 400g Abrasive



Date 2024-04-03							
	Surface Area	0.078715746					
RPM= 2500	Abrasive Concentration=	400g					
Temp= 102 °C	Time (h)=	1					
	Iteration X	Weight lost (g	Predicted wear rate	Real Value	Relative True Erro	Desired RTE (<15%	Relative Approx. Error
	Iteration 1	0.85	35.03463963	32.81	6.78037%	15%	
	Iteration 2	0.84	34.6224674	32.81	5.52413%	15%	1%
	Iteration 3	0.90	37.09550078	32.81	13.06157%	15%	7%
	Iteration 4	0.82	33.79812294	32.81	3.01165%	15%	9%
	Iteration 5	1.00	41.21722309	32.81	25.62397%	15%	22%
	Avg	0.88	36.35359077	32.81	10.80034%		9.78986%
				Avg	10.80034%		

Figure 14 Optimum Abrasive Concentration



In conclusion, the optimum abrasive concentration for this testing was estimated to be at 225g.

Conclusions and Recommendations for Future Work

Conclusion

In conclusion, this project served as a valuable group experience. The group learned how to effectively govern themselves as a proper engineering team; setting deadlines, assigning tasks and solving conflicts were just some of the skills developed during this project.

Future Work

Fortunately, the project was left off in a very accessible and developable state. With the final prototype came a working framework to easily build off and continue refinement.

We managed to create a regression model detailing the linear relationship between the amount of abrasive in the AETS and the wear (erosion) rate of the sample. However, this regression had to be linear as not many data points were able to be collected. Therefore, a simple next step to take would be to find more data points to further develop the relationship and see if the relationship is exponential. More importantly, a point of diminishing returns can be found, where the amount of abrasive added starts to yield less dramatic results and an optimal amount of abrasive can be found.

There is also the possibility of more variance (different variables). Since the AETS has a PWM, the RPM can also be tested as an extra independent variable in conjunction with the abrasive to observe an even stronger effect on wear rate. Furthermore, different abrasives can be tested, and their relationships can be analyzed to determine the most effective abrasives for increasing wear rate (erosion).

Bibliography

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APPENDICES

APPENDIX I: Design Files

This document is a compact summary of all previous project and design work (deliverables A-H). The deliverables referenced below work through the design process in order of Empathize, Define, Ideate, Prototype, and Test; showing our process of arriving at the final design.

MakerRepo Link: https://makerepo.com/AhmadQadori/1972.rock-n-rode

Table 3. Referenced Documents

Document Name	Document Location and/or URL	Issuance Date
Deliverable A	https://makerepo.com/AhmadQadori/1972.rock-n-rode	21/1/2024
Deliverable B	https://makerepo.com/AhmadQadori/1972.rock-n-rode	28/1/2024

Deliverable C	https://makerepo.com/AhmadQadori/1972.rock-n-rode	04/02/2024
Deliverable D	https://makerepo.com/AhmadQadori/1972.rock-n-rode	11/02/2024
Deliverable E	https://makerepo.com/AhmadQadori/1972.rock-n-rode	25/02/2024
Deliverable F	https://makerepo.com/AhmadQadori/1972.rock-n-rode	3/3/2024
Deliverable G	https://makerepo.com/AhmadQadori/1972.rock-n-rode	10/03/2024
Deliverable H	https://makerepo.com/AhmadQadori/1972.rock-n-rode	24/03/2024