Metal Impingement Erosion Laboratory Experience

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Abstract

Metal impact erosion is a common problem in the world today. This erosion is caused by the impingement of solid particles that are carried in a transport fluid on to a metal surface. Depending on the hardness of the metal and intensity of the impact determine the magnitude to the erosional process. A group of international students from the Brazil Scientific Mobility Program (BSMP) were brought together with no knowledge on the topic of impact erosion. They were placed together on an engineering team and through a ten week experimental project; these students were exposed to impact erosion on various metals using a custom designed erosion apparatus. This experimental study allowed the students to compare the obtained data to published results as well as become familiar with industry standard testing procedures. What is presented is a summary of the student's learning experience with respect to the science of impingement erosion.

Keywords

Laboratory experience, erosion, testing, fluid flow

Introduction

Erosion of metal components when exposed to sand laden slurries continue to be a problem in many industries[1]. The cost associated with replacement of eroded parts and the downtime needed when replacing these components often result in large losses to corporations. The ability to model erosional effects on metal components accurately can aid in the reduction of the cost associated with the losses by allowing these metal components to be placed in optimal locations and to allow for replacement to occur before catastrophic failure occurs. After a senior design team built a custom liquid/solid impact erosion test fixture, a group of students from the Brazil Scientific Mobility Program (BSMP) were brought together from different universities around the states to use the apparatus and examine the effect of erosion on different metals. The BSMP is a one-year, non-degree program for Brazilian students to study in the United States. BSMP is part of the Brazilian government's larger initiative to grant Brazilian university students the opportunity to study abroad at US colleges and universities, by offering scholarships to students in the Science, Technology, Engineering and Mathematics (STEM) fields. After completion of an academic year including a summer internship, students return to Brazil to complete their degrees. Three students accepted the program to come and perform research at Mercer University. All were at different Universities and no experience in regards to the project and testing that they were about to undertake. The purpose of this project was to expose the students to a research experience in a 10-week session concerning liquid/solid impact erosion.

Background

Erosion has been studied by many researchers over the years. Ambrosini et al[2] study the erosion behavior of AISI 4140 steel under various heat treatment conditions. Harsha et al[3] carried out research to study the erosion behavior of ferrous and non-ferrous materials and compared the data to various published data and models. Hutchings[4] developed erosion models for normal and oblique angle for various materials and determined the process that causes erosions during the impact events. These include micro ploughing, small craters of indentation, and micro-cracking[5]. Many others took these models and improved upon them via testing [5-11]. The common thread between these models and predictions are the ability to run experiments to test the impact of erosion.

The testing methods are comprised of pneumatic systems and slurry flow systems. Two main types of solid particle erosion testing equipment exist: the centrifugal tester or the injector tester. The centrifugal is based on the projection of particles through centrifugal forces. The particles are fed through the center of a rotating disk accelerated through radial ceramic tubes and ejected onto samples placed around the disk[12]. The second is the most frequently used type testing system. It is based on specifications found in the ASTM standard G76. The particle velocity and particle feed rates need to be measured and controlled before or during testing. The standard test consists of exposing the sample surface for a fixed total mass of powder and evaluating the amount of volume or mass loss. The erosion rate of the tested sample is calculated by dividing the worn volume by the total mass of particles that have impacted the surface[13].

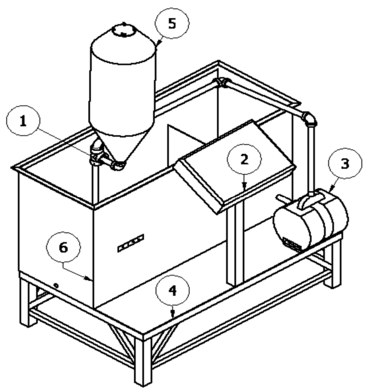
However, this investigator is interested in the differences between the gas injector studies and actual erosion rates observed in liquid/solid environments. Hence, the students were tasked with running various experiments on metal samples using water as the carrier fluid and 20/40 sand as the particulate solid. The 20/40 refers to the mesh sizes that the sand is sieved between and corresponds to sizes 0.017-in and 0.033-in, such that most sand grains are between those two sizes. The students were just expected to run a set number of tests and if time allowed compare to some published data of similar erosion tests. The idea here is that since the fixture had not been fully validated, that comparison studies were needed if this device would be used in any scientific studies. At any rate during the process the students gained knowledge and insight on the aspects of testing, erosion, and computational fluid dynamics.

Test Apparatus

The testing apparatus for the students is the erosion test fixture that was designed by a Senior Design group at Mercer University during the previous two semesters. At Mercer University, seniors complete a two semester senior design sequence where they must first determine a project and perform the analysis of building the project and secondly executing the manufacturing and testing of the apparatus. The design group constructed the erosion test fixture with the components listed in Table 1 and a schematic of the test fixture shown in Figure 1.

Table 1: Erosion Test Fixture Components

Sand Input Method	Auger System
Pump Selection	Double Diaphragm
Controller Type	Arduino Mega 2560
Motor Type	Brushless DC NTM Prop Drive Series 35-36A
Display Screen	LCD Screen



Item Number	Part Description
1	Auger
2	Control Box
3	Diaphragm Pump
4	Frame
5	Sand Hopper
6	Settling Tank

Figure 1: Erosion Test Fixture

This device consists of a settling tank, a sand hopper, pump, nozzle, and auger to deliver the sand and water to the test piece contained in the tank. The pump is a double diaphragm pump that is connected to air pressure within the lab. The air pressure in the lab is adjusted to control the flow rate via an air regulator on the pump itself. The pump will provide the same pressure to the fluid as the air supply it is connected. The fluid is pumped through PVC piping to both the sand hopper and to PVC piping that is connected to the nozzle. The line into the sand hopper fluidizes the sand particles inside of the tank and balances the pressure between the two lines. A bronze auger, Figure 2, rotates and pushes the sand/water slurry from the tank into a junction where the fluid from the clean water line is flow freely.

Figure 2: Bronze Augers

This happens at a vertical section of piping that is directly above the nozzle exit. The nozzle is contained in a metal sleeve and down inside of the tank beneath the sand hopper shown in Figure 3. The nozzle can be run either out of the water or beneath the water when impinging on the metal sample.

Figure 3: Manifold from Hopper to Nozzle

The nozzles in the systems are sand blasting nozzles used in a commercially available deadman sand blasting valve and were purchased from a local hardware store. The ID of the nozzle was checked periodically to ensure that diameter had not increased. Once erosion was seen present on the nozzles, they were removed from the testing apparatus and a new nozzle was added in place.

Figure 4: Ceramic Sand Blasting Nozzle

The entire apparatus is placed on a steel framed covered with a sheet of treated plywood and covered with a waterproof mat. This platform will support all of the system components, connections and allow ease of access for maintenance and operation. One power cord to a standard AC outlet and a connection to an air supply capable of supplying 100 psi is all that is needed to operate the device. The entire device is shown in Figure 5.

Figure 5: Erosion Test Fixture

A control box is located on the stand that is used to control the motor via an Arduino mega 2560 microcontroller hidden in the box. LCD display on the box show the pump pressure and the motor RPM percentage during operation. The motor is a Brushless DC NTM Prop Drive Series and was connected to a gear transmission to step down the motor 8.3:1. The gear assembly is shown below in Figure 6.

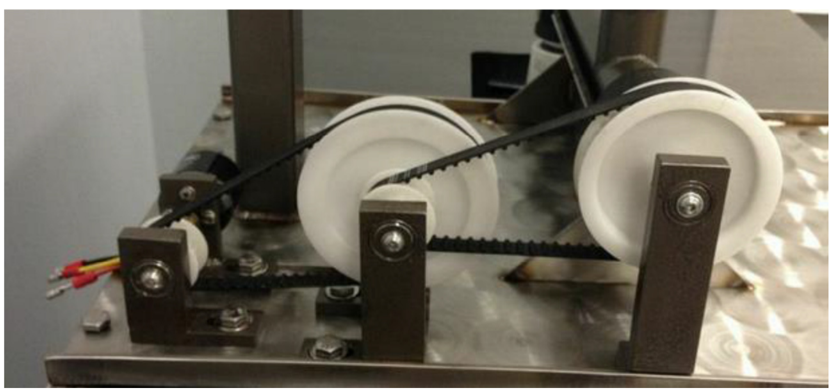


Figure 6: Transmission Assembly

Samples are placed on the sample holder, Figure 7. The sample holder has attachments that allow the angle of the sample to be varied from 30^o, 45^o, 60^o, and 90^o from the vertical axis where the nozzle is ejecting a mixture of sand and water.

Figure 7: Sample Holder

Experimental Procedure

Students were tasked with testing aluminum and steel samples under specified conditions. Both metals were obtained from local mills with the specifications provided. The type of aluminum used was 6061 and the steel used was 4140 steel. Sample coupons were prepared for testing by cutting the bar stock in 3-in by 3-in coupons. In some cases, the bar stock thickness was reduced via grinding or a milling operation. After discussing the project with the students, a set of parameters were listed that could be investigated. The parameters studied were:

- Angle of Impact: 30^o, 45^o, 60^o, and 90^o from the vertical axis of the nozzle
- Metal Type: Aluminum and Steel
- Sand Volume: 2,000 ml, 4,000 ml, 6,000 ml, 8,000 ml, and 10,000 ml
- Specimen and nozzle under water and/or Specimen and nozzle out of water
- Air Pressure: 80, 90, and100 psi
- Nozzle Size: 0.157-in ceramic used for sand blasting applications

With 17 variables listed this meant that 240 experiments would need to be run in order to complete the full matrix. After a little discussion the air pressure variation was reduced to 90 psi only which resulted in 80 trials. This was achievable during the time allotted along with some repetition of test to verify results.

The instructor met with the students the first day to explain the experiments and to demonstrate the necessary equipment to run each test. Operating manuals were given to the students for the erosion test fixture and other equipment needed to move forward. Students were expected to determine the time needed to perform the aforementioned tests and allow time for retests. All relevant data was captured in a project management database, BASECAMP**.** BASECAMP is a project management tool free for academic usages to help with scheduling, data storage, and reporting. BASECAMP can be found on the web at www.basecamp.com. The team worked out a matrix for testing and together with the instructor worked out an experimental procedure to follow for testing. The only inputs from the instructor were slight changes in priority of some tests and repeating select tests to ensure the data collected was consistent.

The experimental plan is shown below:

- Using bar stock provided, test hardness in a few locations to ensure the values meet the specifications provided.
- Cut samples to correct size for testing
- Label metal sample with number.
- Obtain mass/weight of sample using scale pre-experiment
- Place sample on sample holder at desired angle
- Fill setting tank with water.
- Connect Air to Pump and set air pressure to test value.
- Circulate water through PVC lines with sand hopper isolated from main line at low rate.
- Load desired amount of sand into sand hopper
- Replace top seal of sand hopper and open relief valve at the top of the hopper to allow air to escape while filling with water.
- Fill hopper with water until water comes out of relief valve and then close.
- Set valves in proper test position and circulate water only
- Initialize motor from control box
- Open valve that isolates the sand/water slurry mixture from main line
- Turn on motor and set at predetermined RPM for test.
- Run test until sand is completely out of sand hopper.
- Remove sample and label with date, time, and orientation
- Flush system completely
- Dry sample and obtain weight/mass on scale.
- Attempt to measure the dimensions of the eroded piece.

Uncertainty, safety, and data collections procedures were discussed and other general questions answered. After watching the students complete a few sample tests, they were left to accomplish the aforementioned tasks. To run one sample took on average 10 to 15 minutes, with about 1 to 2 hours of pre-test preparation and post-test cleaning. Needless to say sand in a workspace leaves a mess and more importantly without cleaning the system properly, damage and skewed results can occur.

After running multiple tests, the students determined the following data was actually measureable and reportable on a per test basis:

- Sample Mass before test
- Sand Volume before test
- Sample Mass after test
- Some dimensions of eroded spot, but this became more difficult
- Test duration
- Flow pressure
- Observations during tests

Student Learning

After a few tests, the students started reducing the time for pretest and post-test activities. They were able to discover more efficient ways of ensuring the lines and tank were clean. This included changing the valve sequencing to the flushing procedure. They were aggressive with the number of tests run per day initially, and once they figured out the actual time needed per test, they were able to easily proceed through the matrix. After some of the initial tests, it became evident that the uncertainty of the scale used to measure the weight before and after testing was larger than the mass loss in some cases. So the students sought out more accurate scales to use. Also since it was three students working together, the students were able to perform the tests very efficiently.

When comparing the work ethic and preparedness to traditional undergraduate students at Mercer University, they could be ranked in the top third using the same rubrics used in typical assessment techniques for a lab based class. Communication and writing skills would lag behind since English is not their native language, but scientific approach and thoroughness would allow them to be rated slightly higher than traditional students in the same year of schooling.

Actual student performance was measured via the experimental plan, test performance, data analysis, weekly reports, and group poster at the end of the project. The students separated the work load and provided more than adequate information for each assessed group listed. Some of the work is presented in the next section.

Experimental Data

The students looked at the difference of angle of impact on each type of metal. The first two plots shows the variance of angle on the magnitude of the erosion. Figure 8 shows the erosion amount increasing to an angle of about 60^o and then decreasing as the erosion sample became normal to the nozzle with an aluminum sample. While in Figure 9, the steel had its maximum erosion at 45^o and then decreased.

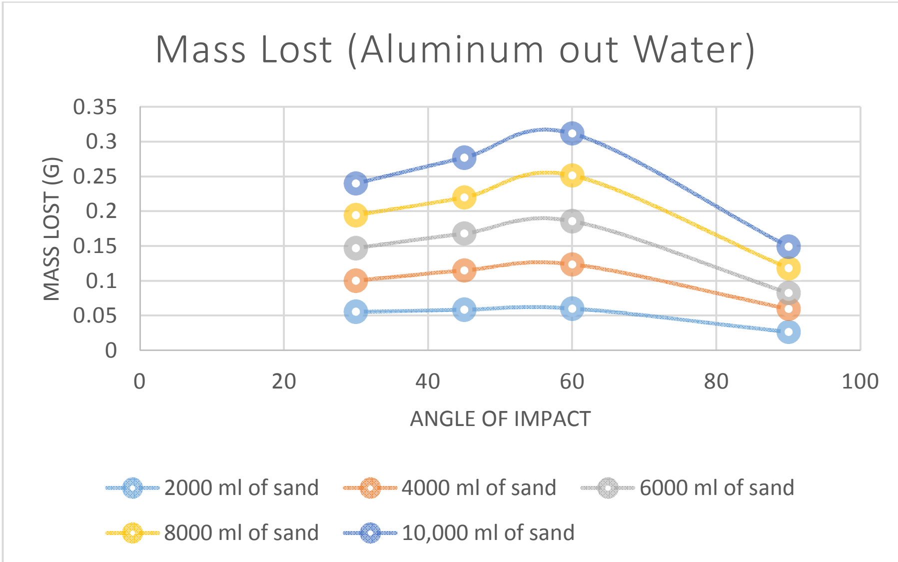


Figure 8: Mass Lost with Aluminum

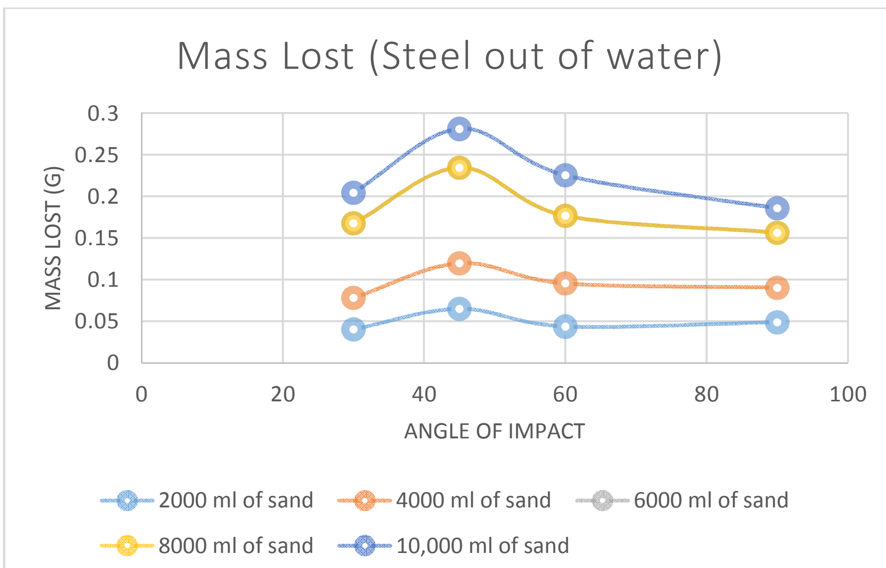


Figure 9: Mass Loss with Steel

Hutchings has a plot in his paper that shows what is to be expected from erosion versus angle for brittle versus ductile metals, Figure 10. The data in this study agrees with that plot qualitatively; however, the angle of maximum erosion does not match the plot.

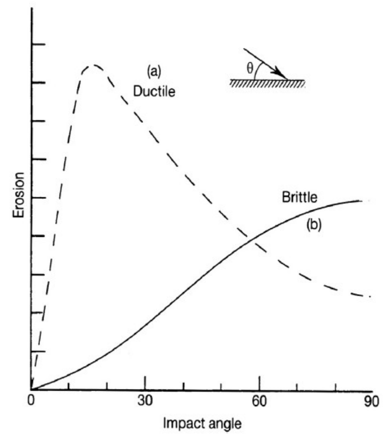


Figure 10: Erosion Dependence on Angle[14]

Some of this is due to uncertainty of the measurements obtained. Other reasons that the data does not completely match is probably due to using liquid/solid flow versus gas/solid flow. Regardless, this illustrates the type of information that can be used and obtained with the test apparatus.

Another interesting observation occurred, when the samples and nozzle were both submerged in the water, the maximum point of erosion becomes the minimum point of erosion with both metals. These tests were repeated with similar results. Representative plots are shown in Figures 11 and 12. The thought here was that due to the nozzle being submerged, the velocity of the sand particles was decelerated. And the liquid layer acted as a buffer from the erosion.

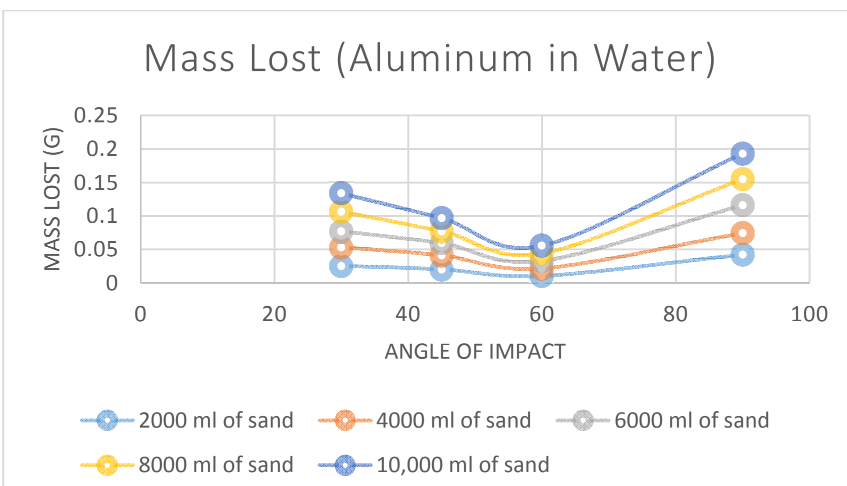


Figure 11: Mass Loss with Aluminum

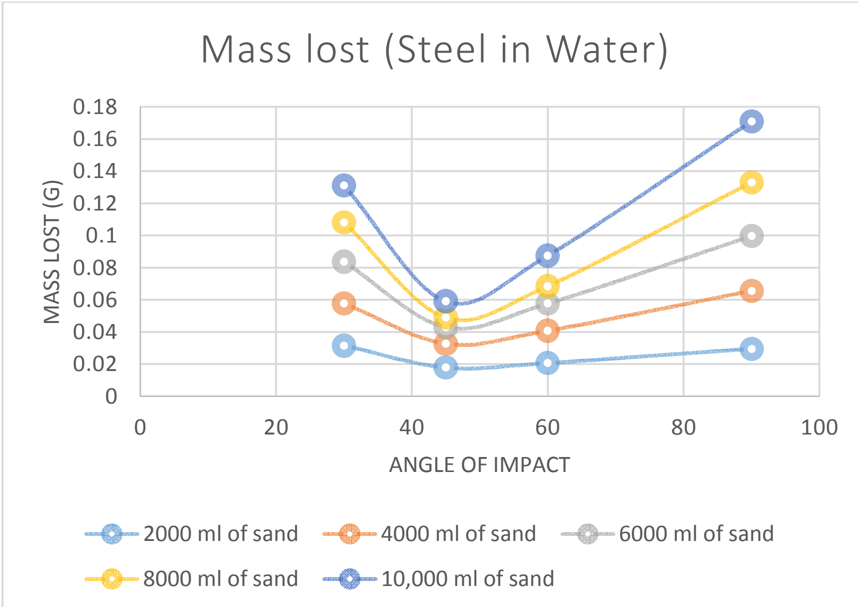
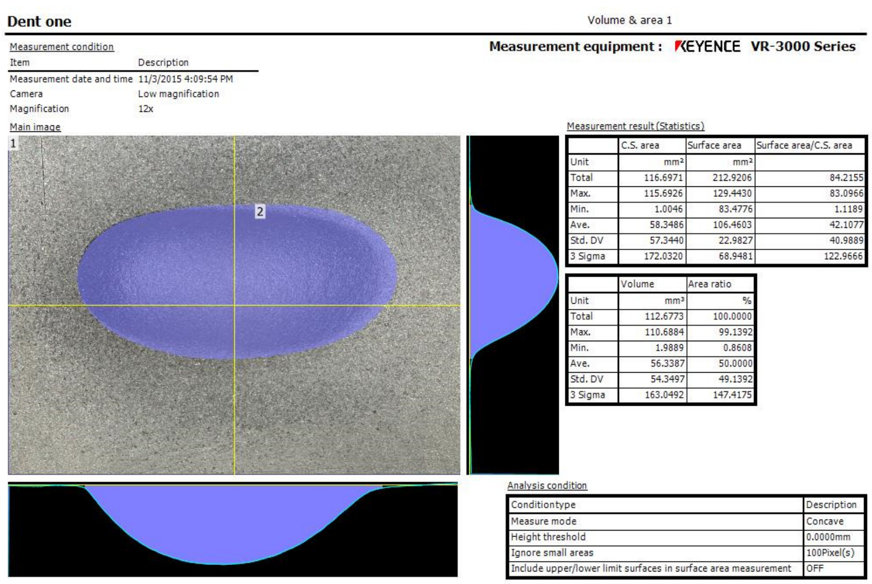


Figure 12: Mass Loss with Steel

The reason the maximum changes to a minimum is a little confusing and needs to be studied further too really understand why this transition occurred. Some of the eroded pieces were measured using a Keyence one shot 3-D Measuring Macroscope VR-3200. This device measures light as it bends over the geometry as a profilometer would use a stylus to measure the imperfection. Using this device, the actual volume measurement of lost material can be measured to determine an erosion rate.



Dent one — Volume & area 1

Measurement equipment : KEYENCE VR-3000 Series

Measurement condition

Item	Description
Measurement date and time	11/3/2015 4:09:54 PM
Camera	Low magnification
Magnification	12x

Main image

Measurement result (Statistics)

	C.S. area	Surface area	Surface area/C.S. area
Unit	mm²	mm²	
Total	116.6971	212.9206	84.2155
Max.	115.6926	129.4430	83.0966
Min.	1.0046	83.4776	1.1189
Ave.	58.3486	106.4603	42.1077
Std. DV	57.3440	22.9827	40.9889
3 Sigma	172.0320	68.9481	122.9666

	Volume	Area ratio
Unit	mm³	%
Total	112.6773	100.0000
Max.	110.6884	99.1392
Min.	1.9889	0.8608
Ave.	56.3387	50.0000
Std. DV	54.3497	49.1392
3 Sigma	163.0492	147.4175

Analysis condition

Conditiontype	Description
Measure mode	Concave
Height threshold	0.0000mm
Ignore small areas	100Pixel(s)
Include upper/lower limit surfaces in surface area measurement	OFF

Figure 13: Image and Measurement of Erosion

This information together can be used to create erosion rates versus impact angles and fully compare to published data. This is just a small sample of the data collected and analyzed. This data will be compared to published data of steel and aluminum as part of another study within the coming year and hopefully published in a technical journal once the trends are fully understood. The purpose here is to illustrate the value of the learning experience of both students and faculty in these situations.

Conclusions

The students involved in this study essentially went from having very little experimental background to being able to fully perform complex tests with no aid within a very short time frame. They were able to develop experimental test matrix determine number of tests needed to be run and towards the end of the research period, identify items that either needed to be retested or improved. They were able to analyze the data obtained and present the data in a form that was easy for most to understand. Although the data has not been fully compared to other researchers published work at this time that is not the goal of this paper. The goal was to show the learning experience obtained from the research experience and to show that the experimental apparatus can be used in more advanced research studies. The data that was obtained when both the sample and nozzle were submerged in water may be an anomaly, but one that should be investigated further with another group at the same conditions as these test and at higher pressures and flowrates. Overall, the methodology that was used by the students illustrates the ability to use the testing apparatus designed by students for actual research in the field of erosion.

Acknowledgements

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