ST. MARY'S UNIVERSITY

School of Science, Engineering and Technology
Department of Engineering

Ultrasonic Welding Repairs on Biosafety Lab Suits

By

Angela Asfura, Anthony Mena, and Joel Vargas

Senior Design Project Presented to the Department of Engineering
In Partial Fulfillment of the Requirements
For the Degree of

Bachelor of Science
In
MECHANICAL ENGINEERING

San Antonio, Texas
April 2023

Supervising Advisor:
Dr. Juan Ocampo
ASSOCIATE PROFESSOR OF MECHANICAL ENGINEERING

ABSTRACT

Ultrasonic welding is a cutting-edge process that harnesses high-frequency vibrations to create a secure and durable bond between two materials. In this project, we sought to explore the potential of ultrasonic welding as a method for repairing Level 4 Biosafety suits. These suits are critical for safeguarding workers who operate in hazardous chemical and biological zones.

Traditionally, the process of repairing these suits has involved using a patch kit and adhesive, which creates rigid areas that compromise the suit's flexibility and durability. Ultrasonic welding, on the other hand, is a non-invasive process that produces a strong and flexible bond between the patch and the suit.

To assess the potential of ultrasonic welding, we designed and conducted a series of rigorous experiments to test the tensile strength and flexibility of the repaired suits. We used a range of parameters, such as frequency, temperature, and pressure, to optimize the welding process. Our findings showed that ultrasonic welding produced a bond with tensile strength slightly less than the fabric itself, but still strong enough to withstand the forces applied to the suit under normal conditions.

ACKNOWLEDGEMENTS

Throughout the development and completion of this project we had the amazing support from our St. May's Engineering faculty and staff. We would like to express our gratitude to the following individuals for their invaluable support in helping us with it. First and foremost, we would like to thank Dr. Juan Ocampo and Dr. Amber McClung for their exceptional guidance, insights, and encouragement throughout this project. Their expertise and support were invaluable in ensuring the success of this project.

We would also like to extend our heartfelt appreciation to Dr. Rafael Moras, Dr. Ozgur Aktunc, Dr. Bob O'Connor, Dr. Abott, Gail Jaszcz, Dr. Morgan Bruns, Vernon Wier and the staff at Texas Biomedical Research Institute who are James Lube, Ray Jaszcz, Mark Behr and Heather Guenther. Their collaboration, assistance and support were instrumental in the completion of this project. Finally, we would like to acknowledge the support of all the individuals who provided valuable feedback, suggestions, and ideas that helped us in completing our project successfully.

Thank you all for your contributions, encouragement, and support in this project. We truly appreciate your efforts and assistance.

TABLE OF CONTENTS

Contents

TABLE OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

1. Introduction

Biosafety Level 4 (BSL-4) laboratory operations require scientists and technicians to wear appropriate biosafety lab suits; Honeywell manufactures the suits used at Texas BioMed. Level 4 biosafety suits are utilized when hazardous substances have been identified and have a high level of hazards to the respiratory system, skin, and eyes. The user's life depends on the suit's integrity and ensuring no breaches. The BSL-4 suits are costly, ranging from about $4,000- $5,000, and their average service life is around four months. This is usually the result of breaches in the fabric or the face shield, resulting in the airtight quality of the suits being compromised. Breaches usually occur from tears, punctures, abrasions, or fatigue. Honeywell sells "patch" kits that contain material similar to that of the suit and the clear face mask. The patches are applied with an adhesive (Loctite 406 or 4902), this requires tedious application, and it usually adds one month to the suit's service life. Issues with patching originate from the rigidness of the adhesive, as it decreases the flexibility of the repaired area, thus causing additional breaches during use. The maximum size that can be repaired at the moment is one inch.

By designing an alternate method to repair suits, we need to test for flexibility, strength, fatigue, and chemical wear. Ensuring that the new process will be more effective compared to the current method, increasing the suit life by two months.

1.1. Company Description

Texas Biomedical Research Institute (TBRI) is a non-profit research institution located in San Antonio, Texas, dedicated to advancing the health of humans and animals through innovative biomedical research. Established in 1941, TBRI has a rich history of groundbreaking discoveries and breakthroughs in a range of research areas, including infectious diseases, genetics, aging, and neuroscience.

TBRI's mission is to improve global human health by supporting research that leads to the development of new diagnostics, treatments, and cures for infectious diseases, metabolic disorders, and other health challenges. With a team of over 200 scientists, researchers, and support staff, TBRI conducts cutting-edge research in state-of-the-art laboratories and facilities, including a Biosafety Level 4 (BSL-4) laboratory, one of only a few in the United States.

TBRI collaborates with a range of academic institutions, government agencies, and industry partners to advance research and translate scientific discoveries into practical applications that improve human health. The Institute also supports education and training programs to develop the next generation of scientists and researchers in the field of biomedical research.

TBRI is dedicated to advancing human health through basic and translational research into nature, causes, prevention, and eradication of diseases. They are sharing their scientific research to protect the global community from the threat of infectious diseases, paving the way to a healthier world where everyone lives free from the fear and effects of infectious diseases. Researchers at TBRI study various topics, such as genetics, immunology, and virology, focusing on emerging and reemerging infectious illnesses that are dangerous to human health. Their scientific discoveries create breakthroughs in medical research to provide better overall global health. Overall, TBRI is committed to advancing the frontiers of biomedical research and improving human and animal health through innovative, collaborative, and impactful research.

1.2. Problem Statement

Design, evaluate and create a new method to repair biosafety suits level 4, used on chemical and hazardous biological zones, as a way to protect users by utilizing data acquired from experimental testing to determine the efficacy as the primary repair method, thus potentially increasing the life of the suit by two months, while giving clear instructions to personnel through the development of a manual.

1.3. Objectives

The main objective is to design and evaluate a system and method to potentially increase the suit life by two months. Our deliverables are:

- Efficacy of ultrasonic repairs on biosafety suits (quantitative data)
- Alternate repair method for the suit, if not ultrasonic weld (quantitative data)
- Design a portable workbench to be able to repair suits in emergencies.
- Process development based on equipment selection, operations parameters (frequency, temperature), setup, and standard operating procedure.
- Create a business model based on results.

- Functional prototype. If welding feasibility proves successful, test repairs will be performed on the whole suit to evaluate method.
- Design a workstation in which the ultrasonic welding repairs will be made.

1.4. Literature Search

1.4.1. Biosafety Suits:

Biosafety level 4 (BSL-4) suit and laboratories are specifically designed to study high-consequence pathogens for which neither infection prophylaxes nor treatment options exist. The hallmarks of these laboratories are custom-designed airtight doors, dedicated supply and exhaust airflow systems, a negative-pressure environment, and mandatory use of positive-pressure ("space") suits. The risk for laboratory specialists working with highly pathogenic agents is minimized through rigorous training and adherence to stringent safety protocols and standard operating procedures.

Level A/4 protection includes:

- Fully encapsulated chemical protective protection suit (full body protection)
- Positive pressure demands full face Self-Contained Breathing Apparatus (SCBA)
- Inner and outer chemical resistant gloves
- Chemical resistant safety boots

Level A is utilized when hazardous substances have been identified and have a high level of hazards to the respiratory system, skin, and eyes. The substances present when using this level of protection are usually known or suspected to cause skin toxicity or carcinogenicity. This ensemble provides the highest available level of respiratory, skin, and eye protection from hazardous substances in a solid, liquid, or gaseous phase. The major impacts of failures in BSL4s come from the exposure to hazardous material or infectious diseases that do not have a cure, and that it compromises the integrity of suits and the safety of user.

Key Features of BSL4 Suits:

- Safe connection and disconnection in the working area thanks to HEPA filter incorporated.
- High protection factor: class 5 according to the EN 1073-1.
- Welded boots and gloves removable.
- Made to measure suit but also available in standard size.
- Excellent comfort thanks to the integral air distribution and magnetic exhaust valves.
- Comply with MNR (Magnetic Nuclear Resonance)

Regulations followed by BSL4 Suits Fabricated by Honeywell:

- EN1073-1 - Protective clothing against Radioactive Contamination-Ventilated suit
- ISO 16603-ISO 16 604 - Resistance against penetration by blood or blood-borne pathogens

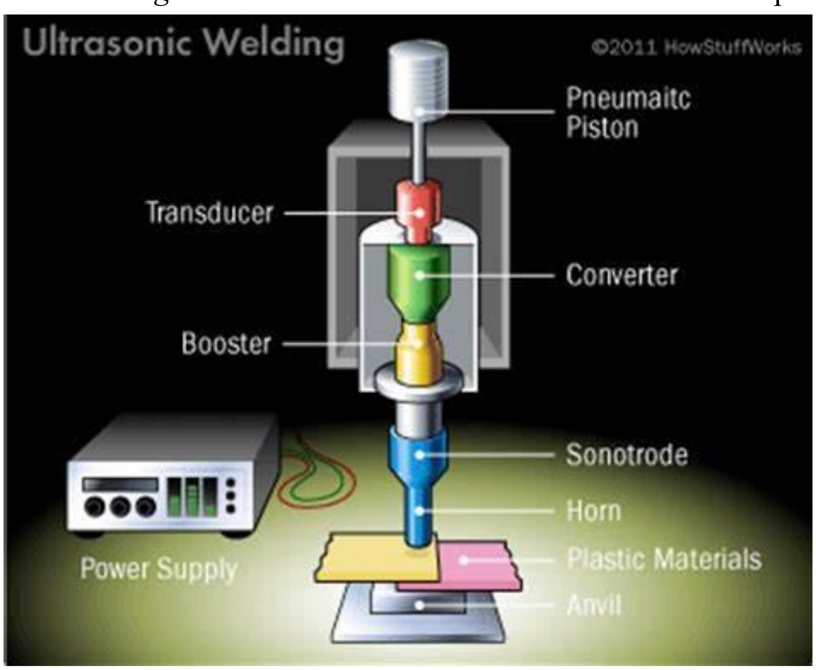
1.4.2. Ultrasonic Welding

This is the process of heat generated by high frequency mechanical motion to joint or reform thermoplastics. This process concerts high frequency electrical energy into mechanical motion. This mechanical motion generates friction heating the mating surfaces to a temperature that forms a molecular bond.

The process of ultrasonic welding is fast and simple. First the parts are oriented in their desired positions. Then the ultrasonic horn is brought into contact with plastic parts and applies a high frequency vibration and compression force. The time it takes to weld the material varies depending on the composition and thickness of the material. This time usually varies from .5-2 seconds. This is called the hold time. It allows the material to be heated to a melting point creating the molecular bond. The vibration then stops, and the horn is removed to let the plastic cool.

There are many advantages to this method of welding. The first being that it is an extremely fast process and can be repeated very quickly, increasing the production rate drastically. It is also very accurate and can be used for small precise welds on thermoplastics.

There are several different components that make up an ultrasonic welder. The main piece is the power supply, as shown in *Figure 1:* Schematics of Ultrasonic Welder. This part of the machine



takes a low frequency electrical current and turns it into a high frequency electrical current. It then passes through the transducer creating a high frequency ultrasonic vibration. Their high frequency vibrations are still really actively weak, so a booster is required to amplify the vibrations. Once the vibration has reached its desired output it passes through the horn. The horn is the metal tip that transfers the vibration to the material being welded. To ensure that the pressure between the horn and material is adequate for achieving a proper weld, an anvil is used to help generate friction.

Figure 1: Schematics of Ultrasonic Welder

There are two different styles of ultrasonic welders that would be applicable or our use. The first would be a tabletop version. This style consists of the power supply that connects to a stand that holds the ultrasonic stack. The ultrasonic stack is moved up and down on a shaft that presses the material to the anvil or nest. The second style that we can consider is the handheld version of the ultrasonic welder. This version is lightweight and portable. It holds the ultrasonic stack in a handheld device that looks similar to that of a gun with a triggering mechanism on it. The use of the anvil for the handheld machine is necessary to help create the required friction for the weld.

The prices of the tabletop welders vary from about $10,000-$45,000 depending on the brand and the machines capabilities, as seen in *Figure 2*: Branson 2000 IW + Ultrasonic Welder ($15,000.00) . The handheld ultrasonic welder ranges from about $5,000-$12,000, as seen in *Figure 3*: Branson LPX Handheld Ultrasonic Welder ($11,000.00).

Figure 2: Branson 2000 IW + Ultrasonic Welder ($15,000.00)

Figure 3: Branson LPX Handheld Ultrasonic Welder ($11,000.00)

1.5. Problem Constraints and Requirements

The requirements and constraints for developing a new repair method for bio suits are of utmost importance to ensure the safety and longevity of the equipment. Primarily, the repair method must show evidence of improvements through quantifiable data produced through mechanical tests. Evidence such as increased tensile strength from the original method and extended life of the bio suit, while also being a cost-effective and time-efficient solution.

Additionally, the method must be easy to manage for introductory level technicians and must not damage the suit in any way. However, there are certain constraints that must be taken into consideration, such as the limitation of fixing breaches no bigger than 2 inches in diameter and ensuring that the repair time does not exceed 2 hours. All these requirements and constraints are essential to creating a successful and reliable repair method for bio suits.

1.5.1. Requirements

- Quantifiable Results from Patch vs. Ultrasonic weld tests
- Welds will be tested for tensile strength (where σ is the stress), such that $\sigma_{weld} > \sigma_{Patch}$ can be consistently demonstrated.
- Must be a cheaper long-term investment (patch Kit costs $150.00 does 10 repairs, new suit costs $5,000.00)
- Must potentially increase the life of bio suit from (X hours) to (2X hours)
- The repair time will not exceed an hour.

- The suit repair methods should be manageable by introductory level technicians.
- New repair method should be more flexible than Loctite glue.

1.5.2. Constraints

- The material we use must be polyester coated with PVC (same material as the suit)
- Cannot fix breaches bigger than 2 inches in diameter.
- Repair method must be able to fix all breeches under 1 inch.
- The repair time will not exceed 2 hours.
- New method should not damage the suit in any way.
- A soft budget of $10,000.00

2. Proposed Solutions

There are many approaches to finding the solution to a specific problem. In this case, the main problem consisted of having issues with the integrity of the Biomedical suit in several areas. Like many products, the Biomedical suit should have had an intended average lifespan set by its designers or manufacturers, however this information was not disclosed and all attempts to contact the manufacturer and retrieve this information proved to be futile. A certain quick-fix solution exists in which patches of the same material are placed over breaches on the suit and joined together using super glue. This is the solution that Texas BioMed had been using prior to the commencement of this project, however this solution would soon create new problems. Using glue to adhere the patch to the fabric changes the mechanics in a localized region of the suit. Instead of the fabric being able to move and stretch freely, a rigid zone is introduced in which various stresses are imposed. With frequent compressive and tensile forces induced by the users of the suit through ordinary human movements, the material is subject to premature failure. The frequency of these stresses and the material's ability to recover are independent studies that are generalized and briefly postulated in this report.

One potential solution that was given by the Texas Biomedical Research Institute was to employ the use of ultrasonic welding. The ultrasonic welding of the patches to the suit would intuitively save time and would also solve the rigidity problem of the previous repair method. The new method of repair would make it feasible for technicians to repair and save the suit from further damage. This would consequently increase the life of the suit; however, it is not enough to merely believe in such a method without rigorous testing and research. The solution is not as apparent as one might think. Some of the possible solutions that we thought about at the beginning included the use of the ultrasonic welder, a heat gun, changing the type of glue they used, and using a special thermoforming tape. As seen in Table 1 we have listed the pros & cons of each one. Which is something that helped us determine what solution approach we wanted to use to find a new repair method for the suits.

	Ultrasonic Welder		**Heat Gun**	**Changing Adhesive Glue**	**Using Adhesive Tape**
	Handheld	**Tabletop**			
Pros	Easier to manipulate in specific areas of the suit. Easier to carry / transport.	Easier to quantify pressure applied.	Heat allows material to bond together.	Fast application time.	Easy to do. Good alternate to ultrasonic welder.
Cons	Harder to determine the amount of pressure that is being applied.	Not viable based on not uniform way of tears. Weird positioning of suit. More expensive.	Suits cannot be exposed to high heat, causes damage (according to Honeywell).	Still creates a stiff area surrounding it.	Would have to change tape after some time.

Table 1: Pros and Cons of Proposed Solutions

3. Solution Approach

Acquiring data from the ultrasonic welding process to determine if it would be a viable repair method was a key objective in this project. The data that was collected throughout the project would be used to compare against the original glue-patch method of repair. However, rendering this data would not be simple and straightforward. There are various factors at play when it comes to determining the cause of the breaches in the biosafety suits. Primarily, the suits are made of several types of polymeric fabrics. For the sake of simplicity and time, we decided to focus on the PVC coated Polyester Tarpaulin which the suits are mainly composed of. Being that this material is a composite made of two distinct polymers with different mechanical properties and manufactured differently, using ultrasonic welding as a repair method would not be as simple as fusing two sheets of polymeric fabric together. Therefore, in this project we attempted to assess the ultrasonic welding method on the reparation of the biosafety suits using different tests that were designed to give us accurate data.

Our first approach to the problem was to determine the various failure mechanisms that exist with the usage of the biosafety suits in the level 4 lab. The fabric which these suits are composed of experience tensile, and compressive forces during usage. In order to gauge how much tensile force this material could withstand; we ran 5 specimens of the material in the MTS uniaxial tensile testing machine. Pneumatic grips were used to ensure that the specimens would be held in place without compromising them. A custom die was made per the ASTM-D412 standard to cut uniformly shaped specimens. The data that was produced was then entered into MATLAB where calculations were made based on the displacement and the force applied. The ultimate strain and ultimate stress were acquired with this data and a stress vs strain curve was produced using the data. Several iterations of the same tests were performed with modifications to the specimens and methods which are discussed in detail in their respective sections.

The pressure that the suit must hold is also important in determining the efficacy of the ultrasonic welding method. A pressure test was designed in order to determine the ultrasonically welded specimen's ability to hold pressure. Several measures were taken into consideration when designing this test such as cost, simplicity and availability. The pressure test produced qualitative data that could tell us whether the welds would provide an airtight seal for the safety of the users of the biosafety suits.

In trying to determine the cause of the failures on the suits, we determined that a chemical test was necessary to ascertain whether the cleaning detergent was affecting the properties of the material. Several iterations of this test were performed to obtain accurate data using varying methods which are discussed in detail in the chemical test section. The chemical test is nothing more than an extension of the tensile test with the specimens being exposed to the chemical before being run in the MTS tensile tester.

In order to quantify the time that it takes for the PVC coated Polyester fabric to fail, a fatigue test is desired. Due to the lack of resources in this project and despite extensive searching for a fatigue testing machine we were unable to conduct a full fatigue test. Although we were unable to produce data from a physical test, we were able to simulate the fatigue test using various known parameters and material properties that we were able to calculate based on the Basquin Model.

To establish a comparative basis in terms of suit life, a method of producing data was first performed by taking the sign in sheets used for entry into the laboratory. Manual data entry was conducted by taking the sign in sheet data for the years 2019 and 2020 and transferring it to excel. Values were obtained and used to compare the life of the suit. A new method of obtaining data much easier was developed through the use of an application, where the original sign in sheet method is replaced by a tablet in which people could sign in with.

4. Design Summary

Since we are working with suits that are protective gear for the user, there are certain standards that this protective gear has to follow based on the Center For Disease Control and Prevention (CDC) Guidelines which is the main testing parameter for our method, pressure testing the welds to ensure there are no air leaks, making the method airtight. After this we need to verify that the welds are going to be able to withstand the maximum forces that the suit is subjected to, which we calculated based on the most strenuous movements that the users do while utilizing the suits. We need to make sure that the weld is going to be able to withstand various uses and not fail prior to the suit being retired (from either damage or age).

In order to determine that ultrasonic welding was a viable repair method, we had to ensure that the welds passed certain criteria while being tested. We decided to test the welds for their strength, their flexibility, how long they would last, and to make sure that they were airtight.

- Airtight Test – Pressure Test
    - This ensures that the integrity of the suit is not compromised. Suits need to be airtight, to prevent air pathogens from coming into contact with the user.
- Fatigue Test
    - Helps determine the wear and tear of suit based on usage, allowing us to determine whether the weld will last a prolonged amount of time.
- Tensile Test

- By utilizing a stress – strain curve, we are able to see the elasticity (deformation) of the material as it is stretched under a tensile load, (not significantly similar to what it goes through).

- Chemical Test
    - Suits undergo chemical cleaning prior to entering and after exiting the laboratory, ensuring that there will not be any repercussions on the weld is ideal.

5. Overview of Design

5.1. Maximum Forces Acting on Suit

Calculations of the maximum forces acting on the suit, based on strenuous movements performed by users. To calculate the force that is acting on the suit in its most tense moments (squatting down puts a lot of tension on the knee and reaching up puts a lot of strain in the back of the arm near the arm pit area) we use Equation 1: Hooke's Law,

$$\sigma = E\varepsilon$$

Equation 1: Hooke's Law

Where,

σ is the axial/normal stress.

E is the elastic modulus or Young's Modulus

ε is the axial/normal strain

To calculate Young's Modulus, we use our stress-strain curve from the material using the MTS. We ran 5 samples of the PVC coated Polyester Tarpaulin material and got the average.

Raw Material			
	Strength (N/mm^2)	**Yield Elongation**	**Young's Modulus (N/ mm^2)**
1	14	23.9442	59.4
2	9.1	17.7582	55.1
3	11.3	20.0036	59.2
4	12.9	23.0826	58.1
5	11.7	20.8792	56.7
Average	11.8	21.13356	57.7

Table 2: Raw Material Values for Young's modulus

To calculate the strain, we had a user inside the suit, and made them go through the motions of the squatting down and reaching up. In the areas of the knees and the back of the arm, we had initial markings, from which we get our L_o (initial length) and as they perform the movements, we observed how the marking moved so we took their measurement to get L_f (final length).

We used the values we get and used them in the following formula,

$$\varepsilon = \frac{L_f - L_o}{L_o}$$

Equation 2: Strain

We ran five different measurements for each of the selected areas, from there we calculated the average, which are the values that we will use.

Knee	1	2	3	4	5	Average
L_O	21.66	23.6	18.31	36.54	29.55	
L_F	22.65	26.71	22.01	39.7	35.01	
ε (mm)	0.045706	0.13178	0.202075	0.086481	0.184772	0.130163

Table 3: Strain Calculations from squatting

Arm	1	2	3	4	5	Average
L_O	22.85	21.94	21.6	31.17	40.04	
L_F	23.8	24.46	23.24	31.58	40.72	
ε (mm)	0.041575	0.114859	0.075926	0.013154	0.016983	0.052499

Table 4: Strain Calculations from reaching up

Using the average strain from squatting from Table 3, we can calculate the maximum force that the suit undergoes when squatting. Using Equation 1: Hooke's Law, we can determine that the Maximum force that the suit is subjected to when the individual is squatting is equal to 7.51 N. Using the average strain from the user reaching up from, Table 4 we calculate that the maximum force that is acting on the suit is equal to 3.029 N. The values found are used as a comparative value for our tensile testing and the force that it undergoes while running fatigue simulations.

Knowing this force allows us to verify that the welds are going to be able to withstand these forces and not tear or be punctured from the added stress. This also gives us a control value to which we should compare our results with ensuring that we are always above it. Additionally, this is the maximum force that the suit is going to be under, which is the maximum force that we are going to utilize during our fatigue testing.

5.2. Pressure Test Design

The purpose of this test is to determine the range of welding parameters that will allow the repairs to be airtight. This is the first test as it will help us to determine one of the most vital characteristics of the welded patch. The best method that was available to us to perform this test was a vacuum chamber. This would allow us to more directly control and measure the pressure in the environment. Other ideas would have also worked but this means the testing mechanism would have had to be fabricated ultimately slowing down the progression of this project. One idea was to design a bracket and plate what would sandwich a sample of the fabric shown in *Figure 4*: Initial design set up for the pressure test. This could have worked but this method would have taken more time to set up and cost around $80.00 for materials.

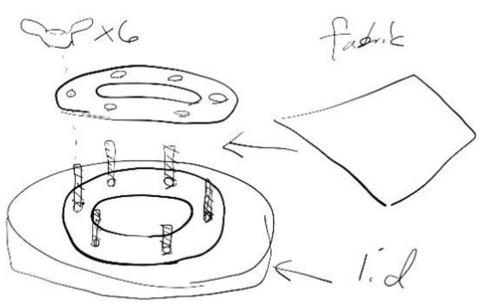


Figure 4: Initial design set up for the pressure test

The samples would be cut in a circular shape with a diameter the same as a lid to a mason jar. The sample would be pressed with a 5mm circular punch to create a breach that would be welded with a patch. The sample with welded patch would then be placed inside the lid of the mason jar and then secured to the glass jar. Ideally, the pressure between the fabric and the jar would create an airtight seal. This set up can be seen in *Figure 5*: Model of Pressure Test Design.

Figure 5: Model of Pressure Test Design

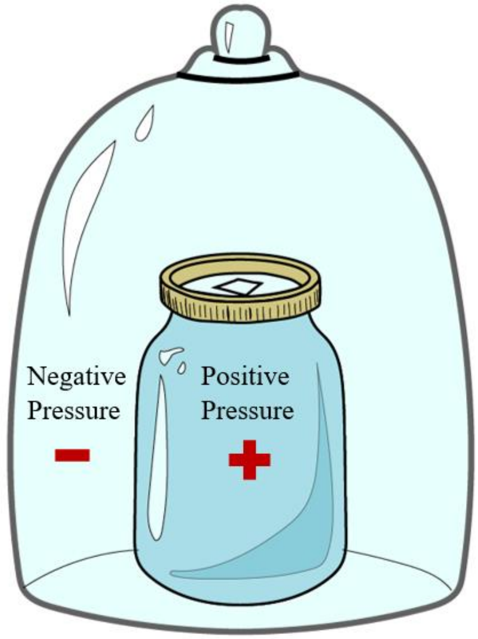


Figure 6: Modified Mason Jar Inside of a Vacuum Sealed Chamber

Figure 6: Modified Mason Jar Inside of a Vacuum Sealed Chamber above shows how the air-tight pressure test will work. This test design works on the basic principles of physics where pressure differences will act as the mechanism to assess the weld and how airtight it is. The modified mason jar is placed inside of a larger sealed container with the specimen loaded. The air on the outside of the mason jar will be evacuated using a vacuum pump. Assuming proper sealing measures are in place in the mason jar and the larger container, the higher pressure inside the mason jar will want to escape and will push on the fabric with welded patch. There is still, however, a diffusion rate present.

The EN 17073-1 standard outlined by Honeywell's gas tight test states that the suit must not diffuse more than 20% of the pressure over a period of four minutes. This was a reference that was used to help design the test itself. However, it is important to keep in mind that the vacuum system used for this test had a natural loss. Additionally, if the samples were placed inside the vacuum incorrectly, they would inure an air leak. Determining if the air leak were occurring from the improper placement of the sample, the weld itself, or the system would be difficult to differentiate.

A visual aid was needed to help identify the air leaks, as seen in *Figure 7*: Bubbles indicating pressure loss at weld seam. After brainstorming some ideas, soap and water would be the most effective methods. It was using soap and water on the top of the weld would allow us to identify where the air leak was occurring on the weld or if it were from the improper placement of the sample. If bubble did not form, then it could be assumed that the air loss was due to the system itself.

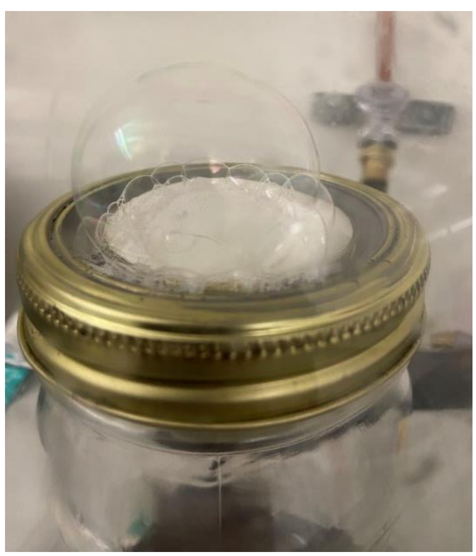


Figure 7: Bubbles indicating pressure loss at weld seam.

The design of the pressure test is detailed in Table 5:

Steps	Action
1	Cut circular samples with a radius of 32mm radius.
2	Create a small perforation in the middle of the circular sample using a 5mm punch. a. This would replicate the suit having a breach
3	Cut a small 1 x 1 in patch.
4	Clean the surface if the anvil and the fabric with isopropyl alcohol.
5	Weld patch in the center of the circular sample at the specified testing parameters.
6	Place the sample on mason jar lid and seal it with a gasket maker.
7	Wait 1 hour for seal to dry.
8	Place the lid on mason jar.
9	Place bubble soap mix on top of the weld (this will let us see if there are any air leaks, if there are bubbles on top of the weld, there are leaks)
10	Place mason jar in table in vacuum chamber
11	Make sure that valves are closed.
12	Turn on pump.
13	Slowly open valve to lo regulate pressure to -0.9 bars.
14	Observe sample to see if there are any bubbles. a. Additionally, observe the gauge to ensure that the system is not losing pressure at a rate greater than the natural loss.

Table 5: Steps for Pressure Test

After the first iteration of this pressure test it was evident that there were a few issues. The most troublesome problem was that most of the welds proved to not be airtight. The technique used to weld the patches was simple. The patch would be subjected to the weld for the specified time and once this time was reached, the welder would stop. This was repeated around all four edges of the patch to form a square as seen in *Figure 8*: Different Types of Welds. R: Overlapping method. L: Encapsulating method. on the right. This method proved inadequate as it did not provide consistent results.

While we did have air leaks from the sides, we also had leaks from the welds in the lower energy range (300-420 Joules(J)) which where all of our initial parameters based on the suggestion of 360 J and 100% amplitude were the best settings according to Sonitek (the people who sold us the welder). To get rid of the air leaks form the sides of the set up, we created a gasket using Permatex Ultra Grey, which was successful. But we still had air leaks in the weld itself, which created the bubbles.

Our first trial of the pressure test involved only welding the corners and edges of the patch, this resulted in air leaks every time. We then decided to try a new method that involved overlapping the welds themselves in order to get a better restriction of the air that could escape from the tear. In *Figure 8*: Different Types of Welds. R: Overlapping method. L: Encapsulating method. we can see the difference in both the overlapping method and the encapsulating one. On the left we have the overlapping method and on the right the encapsulating method.

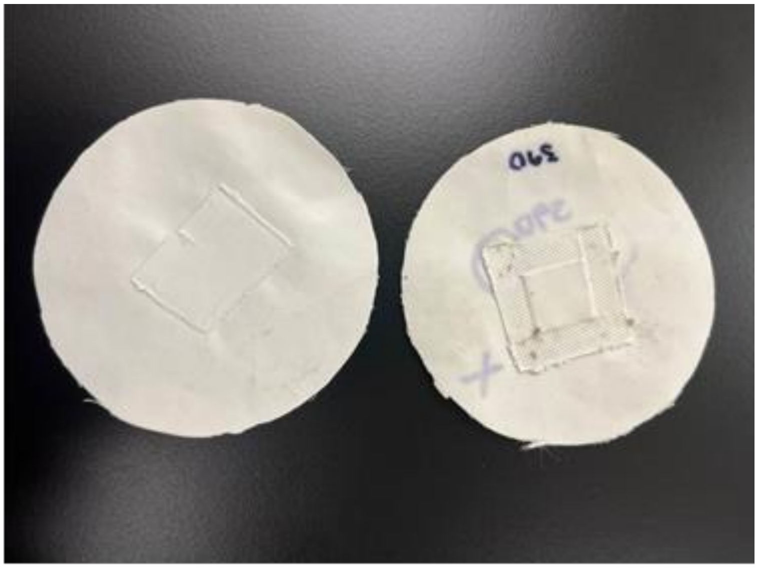


Figure 8: Different Types of Welds. R: Overlapping method. L: Encapsulating method.

The way we quantified our results was based on a pass/fail test as seen in Table 6. The first 4 energy samples did not pass the test having an average of 33.33% of success, here we varied the energy applied to the weld, having a constant pressure level. From there we move to the second set of values having the Energy at 1000J and varying the pressure applied to the weld, we had an average of 66.66% chances of the weld being airtight. The last set, under continuous energy at 6% pressure, was the most successful, being airtight and maintaining pressure in all 3 samples. The vacuum system had an average loss of about 0.0012 bar per second or 0.072 bar per minute.

Pressure Test			
Sample	**1**	**2**	**3**
330	Pass	Fail	Pass
360	Pass	Fail	Fail
390	Pass	Fail	Fail
420	Fail	Fail	Fail
1000 @ 8%	Pass	Fail	Pass
1000 @ 12%	Fail	Pass	Pass
Continuous Energy			
CE @ 6%	Pass	Pass	Pass

Table 6: Pass or Fail Results for Pressure Test

5.3. Design and Adaptation of Tensile Test

Tensile testing allows us to determine the maximum strength of the material and how much it can stretch under a load before breaking. Based on the tensile testing, we can determine the ultimate strength of the PVC coated Polyester Tarpaulin for the material itself and a specimen that has been modified as an attempt to assess the weld strength performed with the ultrasonic welder. A different specimen was also modified to assess the strength of the Loctite 406 glue. The results of this test will be used in part to determine the efficacy of using the ultrasonic welder over the original repair method.

To run these tests correctly and obtain accurate data that was valid, we adhered to one standard for the tensile testing aspect of this project. The ASTM D412 standard was used as a guideline to run these tests. Everything from the dimensions of the test specimens to the calculation procedures were followed. A special cutting die was ordered to produce uniformity and maintain accuracy with each specimen. The die can be seen on "

Figure 9: Type A tensile test specimen die per ASTM-D41. It is used with a mallet and creates a clean cut for each specimen. Please refer to Table 7.

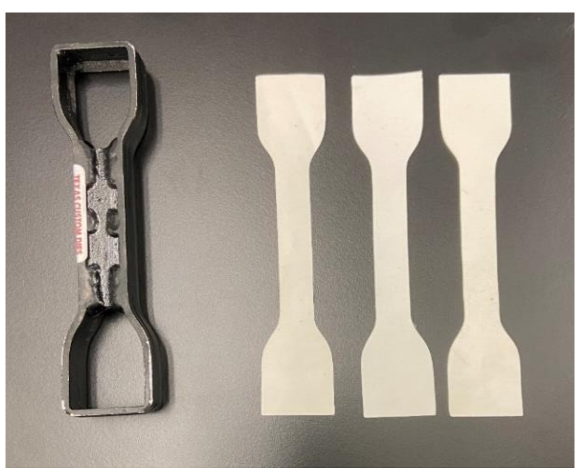


Figure 9: Type A tensile test specimen die per ASTM-D412

Steps	Action
1	Cut samples using dumbbell die type A on cutting mat with a mallet. (Die A was chose given the standards outlined in ASTM D412)
2	Prepare 5 samples for the 5 different welds. a) In the middle of the sample, make a single clean cut directly in the middle of a sheet of material large enough to cut out five specimens. b) Cut a rectangular strip of material that is 1" thick and long enough to cover the entire length of the sheet in step "a." c) Clean the surface of the material and anvil with 70% isopropyl alcohol to remove and contaminants that may affect the weld. d) Lay the material on a clean flat surface. e) Next, place the long 1" strip on the sheet of material so that the cut is centered on the middle of the patch. f) Tape down the ends of the patch to help prevent it from moving during the welding process. g) Weld the patch given the outlined parameter for the test.
3	Prepare 5 Loctite glue samples. a) In the thin section of the sample make a clean cut directly in the middle b) Use a patch of the same width and a length of 1 in c) Set patch with Loctite glue.
4	Prepare 5 samples that have been chemically exposed to Micro-Chem a) Use samples that underwent chemical exposure. b) Let samples dry.
5	Prepare 5 samples of the raw material (control samples).
6	Test samples with tensile test machine a) Use pneumatic grips. b) Run tensile test. c) Ensure that load and crosshead area are zeroed out. i. Set grip separation to 500 mm/min. ii. Measure thickness of sample in 3 different areas and input average value.

	1. It needs a value higher than 0.36 mm (which is our thickness) 2. Add an integer before 0.36 mm = 1.36 mm iii. Set width of sample to 12 mm
7	Upload raw data to MATLAB/excel code.
8	Plot stress – strain curve
9	Determine tensile strength, ultimate strength, and yield elongation.

Table 7: Steps for Tensile Test

The machine that was used for the tensile testing machine can be seen below in *Figure 10*: MTS tensile testing machine with pneumatic grips. Visible in the picture is the pneumatic grips that were used for the test. These pneumatic grips were used for this test abiding for the guidelines in the ASTM-D412 Standard. The pneumatic grips would facilitate accurate testing of the fabric.

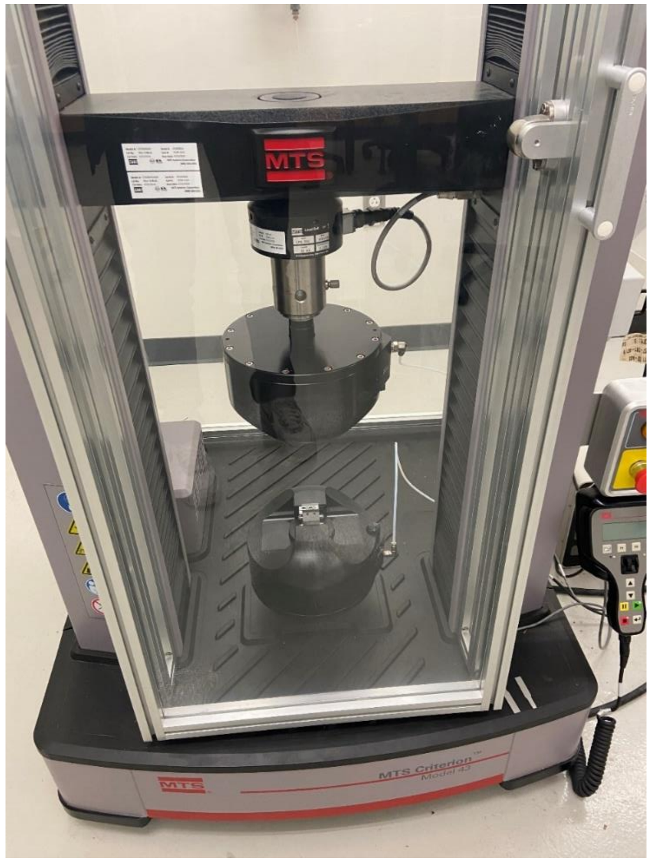


Figure 10: MTS tensile testing machine with pneumatic grips

5.4. Chemical Test

To accurately identify the different causes of the breaches happening in the suits, we attempted to simulate some of the processes that the suit underwent while entering and exiting the lab. One of the processes that every suit must undergo is the decontamination showers. The decontamination showers serve to avoid contamination inside of the lab and outside of the lab. This operation consists of a chamber in which the lab operators are subjected to showers of a solution consisting of Micro-Chem Plus Detergent and water. The process begins with a shower of water for approximately 2 minutes and then a shower of 5 % diluted Micro-Chem Plus for 3 minutes. Finally, the suit undergoes another rinsing process of 2 minutes with water. Each suit undergoes the same process multiple times in its lifespan going into the lab and out.

The chemical test was conducted to investigate the effects of the frequent exposure of the bio safety suits to the showers of detergent. More specifically, does Micro-Chem Plus detergent affect the mechanical properties of the PVC coated polyester which the suits are made of? To answer this question, we set out to design an experiment that could accurately describe these effects. Although it is difficult to completely replicate the decontamination showers, we designed a method that is a good approximation of the process based on the information already given.

Having some information on the biomedical suits is useful as it will influence the design of the experiment and aid us in acquiring answers. Since we already compiled data from the sign-in sheets, we took comparison values that can be used as a basis for the design of this experiment. In this case, the number of instances that the suits entered the lab was retrieved from the sign-in sheets provided by Texas Bio Medical Research Institute. The maximum number of instances that a suit was used was recorded as 149 instances. The way this number was obtained is mentioned in detail on the data acquisition portion of this report. This number was then multiplied by the duration of the Micro-Chem Plus detergent application in the decontamination shower. This duration is approximately 3 minutes of exposure time. The total time was then multiplied by two to simulate both entrance and exit and then it was converted from minutes to hours. The maximum amount of compiled time calculated for the years 2019 and 2020 in the decontamination showers was approximately 14.9 hours. This is strictly the detergent application portion of the shower. The rinsing portion was left out because we only wanted to focus on the effects of the Micro-Chem Plus detergent on the fabric. Although, it should be noted that leaving out the intervals of detergent application and rinsing, plus the drying of the fabric from this experiment may remove from the exactness of the decontamination process experienced at Texas Biomedical Research Institute. The design of the chemical exposure experiment consisted of the following:

Steps	**Action**
1	Place 5 samples in the tray
2	Pour 500 ml of 5% diluted mix of water and micro chem into the tray.
3	Cover tray with aluminum paper to protect from the elements.
4	Let samples soak in chemical for 22.5 hours.
5	Remove samples from the tray.
6	Rinse with water.
7	Allow samples to air dry.
8	Test samples in the tensile testing machine.

Table 8: 2-Sided Chemical Test

Figure 11: Fully Submerged Chemical Test

We realized that this wasn't effective, as the suit's fabric is not exposed on both sides. Based on this we redesign our testing to test the fabric under the right conditions. We then proceeded to submerge the fabric on one side only. The steps we took to get the one-sided chemical test were the following:

Steps	Action
1	Cut a piece of fabric approximately 30 inches by 40 inches.
2	Line the plastic pan with the fabric, securing it with rubber bands so it would create something similar to a pool.
3	Pour the Micro Chem diluted at 5%
4	Wait 22.5 hours
5	Pour chemical out
6	Rinse fabric with water
7	Wait for fabric to dry
8	Cut the samples using the die

9	Test sample in the tensile testing machine

Table 9: One-Sided Chemical Test

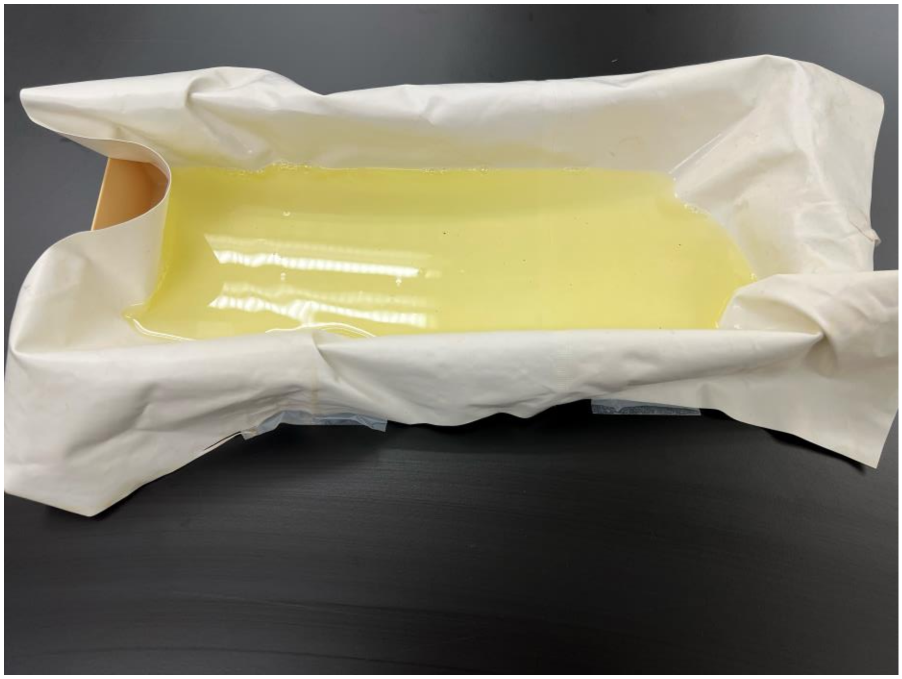


Figure 12: One- Sided Chemical Exposure

5.5. Fatigue Test

The fatigue test helps us determine the safe life span of the ultrasonic repair before it fails. This is an important analysis that we need in order determine if repairing the suits using this method is better than the previous.

Fabrics are commonly tested using a bi-axial testing machine. This allows you to create all the stresses that are going to be acting on the suit. The woven pattern being one of the factors that makes a biaxial test necessary. Due to the lack of proper equipment to test the fabric under the needed stresses, we determined that running a simulation, which we can create this, would be the best approach.

Using computer simulation techniques such as Finite Element Analysis (FEA) to predict the fatigue behavior of the material, we can predict the stress and strain distribution in a component subjected to cyclic loading, and the fatigue life can be estimated using fatigue analysis software. However, FEA requires accurate material properties, which can only be obtained through physical testing. We were able to acquire our material properties from the tensile tests. We were able to determine the Young's Modulus, Tensile Strength, Yield Strength, and Poison's Ratio.

There are mathematical models that can predict how a material will behave based on fatigue. The most common models used for predicting the fatigue behavior of materials are the Coffin-Manson and Basquin models. This model helped us get the predicted SN curve, that we used to input into SolidWorks for us to be able to run the fatigue simulation.

5.5.1. Coffin-Manson Model

The Coffin-Manson model relates the number of cycles to failure to the plastic strain amplitude of the material. The model is based on the assumption that the plastic strain amplitude is the dominant factor affecting fatigue life. The Coffin-Manson model can be expressed as:

$$N = \left(\frac{1}{A}\right) * (\varepsilon_p)^{-b}$$

Equation 3: Coffin-Manson Model based on Number of Cycles until Failure

Where,

N is the number of cycles to failure

A is the fatigue strength coefficient

b is the strain hardening exponent

ε_p is the plastic strain range

The fatigue strength coefficient, A, is a material property related to the material's fatigue strength coefficient, it represents the maximum stress the material can withstand for a specified number of cycles, it is also knowns as the fatigue limit of endurance. A high fatigue strength coefficient corresponds to a longer fatigue life.

A, the fatigue strength coefficient, is not the same in the Basquin Model compared to the Coffin-Manson Model.

To calculate it we use the following equation,

$$A = k_f * {\sigma_u}^n$$

Equation 4:Fatigue Strength Coefficient CMM

Where,

A is the fatigue strength coefficient

k_f is the empirical constant (typically between 0.4 – 0.7)

σ_u is the tensile strength of the material

n is the slope of the SN curve (typically between 3 – 5)

The strain hardening exponent, b, is the material's hardening exponent, which the material hardens as it is subjected to plastic deformation. A higher strain hardening exponent corresponds to a shorter fatigue life. It is the rate at which a material hardens as it deforms. To calculate this you do the following,

1. Do tensile test
2. Get stress-strain curve
3. Calculate yield strength
4. Calculate true stress and true strain
    a. True stress = engineering stress *(1 + engineering strain)
    b. True strain = ln (1 + engineering strain)
5. Plot in log-log scale
6. Slope of linear region is the strain hardening exponent

The graphs can be found in Appendix B.

The plastic strain range, ε_p is the difference between the maximum and the minimum plastic strain values that occur each cycle. To calculate,

$$\varepsilon_p = A * (\Delta\sigma)^b$$

Equation 5: Plastic Strain Range

A,b → material constants

$\Delta\sigma$ → stress amplitude

A, the fatigue strength coefficient, is not the same in the Basquin Model compared to the Coffin & Manson Model.

The Coffin-Manson model can be used to estimate the fatigue life of a material for a given strain amplitude or to predict the strain amplitude required to achieve a certain number of cycles to failure.

5.5.2. The Basquin Model

The Basquin model, on the other hand, relates the stress amplitude to the number of cycles to failure. The Basquin model assumes that the fatigue life of a material is controlled by the stress amplitude. The Basquin model can be expressed as:

$$N = (\frac{S}{C})^b$$

Equation 6: Basquin Model based on Number of Cycles until Failure.

Where,

N is the number of cycles to failure

S is the stress amplitude

C is the fatigue strength coefficient, also known as Sf

b is the fatigue strength exponent

S, the stress amplitude, can be calculated by

$$S = \frac{highest\ stress - lowest\ stress}{2}$$

Equation 7: Stress Amplitude

The fatigue strength coefficient, Se or Sf, is a material property that represents the stress amplitude required to produce aa given number of cycles to failure. To get this value, we need to perform a fatigue test on the material, in our case an elastomer. The most common testing method for elastomers is the tension-compression test, in which the elastomer is subjected to cyclic loading in tension and compression. The number of cycles to failure is recorded for each stress level, and the data is analyzed using a statistical method such as the staircase method or the up-and-down method to determine the stress level that produces a specific number of cycles to failure. The stress amplitude at this stress level is the fatigue strength coefficient, C. It can also be found in a materials database. To calculate it based on the stress-life method, involves plotting the applied stress amplitude S, versus the number of cycles N, on a logarithmic scale. The SN Curve is then used to determine the fatigues strength coefficient, which represent the stress amplitude at a specific number of cycles to failure, typically 10^7.

The equation to calculate the fatigue strength coefficient,

$$C = S * (\frac{N}{10^7})^{-\frac{1}{b}}$$

Equation 8: Fatigue Strength Coefficient BM

Where,

S is the stress amplitude

N is the number of cycles to failure

b is the fatigue strength exponent

This equation assumes a power relationship between stress amplitude and the number of cycles to failure, which is the fatigue loading of the material.

The fatigue strength exponent, b, is a material property that represents the sensitivity of the material to changes in stress amplitude on fatigue life. It relates the stress amplitude to the number of cycles. It determines the slope, so it affects the rate at which the number of cycles to failure decreases with the increasing stress amplitude. To obtain b, we can perform fatigue testing of the material under different stress levels. The relationship between the stress amplitude S and the number of cycles to failure, N can be expressed as the following:

$$log\, N = log\, C - b * log\, S$$

Equation 9: Fatigue Strength Exponent BM

The slope of linear regression is the value of the fatigue strength exponent, b.

A lower value of b indicates a faster decrease in fatigue life, steep slope. A higher value of b indicates a slower decrease in fatigue life with increasing stress amplitude (flatter slope).

The Basquin model can be used to estimate the fatigue life of a material for a given stress amplitude or to predict the stress amplitude required to achieve a certain number of cycles to failure. It assumes constant amplitude testing.

5.5.3. Running the Coffin-Manson Model

Honeywell employs a unique fabric made from polyester coated with PVC at a weight of 250g/m2. Unfortunately, there is no available information online regarding the material properties of this specific fabric, making it challenging to perform accurate calculations. However, we were able to determine some properties such as the tensile strength, yield elongation, and amplitude stress from previous tests. Nonetheless, we were unable to obtain values for properties like the fatigue strength coefficient, the fatigue strength exponent, the strain hardening exponent, the empirical constants, and the slope of the SN curve. As a result, we had to make initial assumptions based on our literature search on similar materials and select a value in the middle range of the given values.

In the Coffin-Manson model, we began by obtaining the fatigue strength coefficient, A, using Equation 4:Fatigue Strength Coefficient CMM. However, since we didn't have all the required values, we had to make some assumptions. For instance, we assumed the empirical constant, k_f to be 0.3 within the given range of 0.4-0.7. We also had to assume a slope of 3 for our SN curve, based on the range of 3-5. We chose the smallest value for the slope, as it provided the highest number of cycles. Once we determined all the required values, we could calculate the fatigue strength coefficient accurately.

After getting our fatigue strength coefficient, we were able to calculate the remaining terms so we could get our SN curve.

To obtain an SN curve using the Coffin-Manson model, there are several steps that need to be followed. First, the tensile strength and strain hardening exponent of the material need to be determined. Next, the empirical constants A and b for the Coffin-Manson model must be determined. These constants may vary depending on the specific material and testing conditions.

Once these parameters have been obtained, the plastic strain range (Equation 5: Plastic Strain Range) for a range of stress amplitudes (Equation 7: Stress Amplitude) can be calculated. Finally, the resulting values of stress amplitude versus the number of cycles to failure (N) are plotted on a log-log scale using Excel to obtain the SN curve, as seen in *Figure 13*:SN Curve based on Coffin-Manson Model for Raw Material and *Figure 14*: SN Curve based on Coffin-Manson Model for Welded Material.

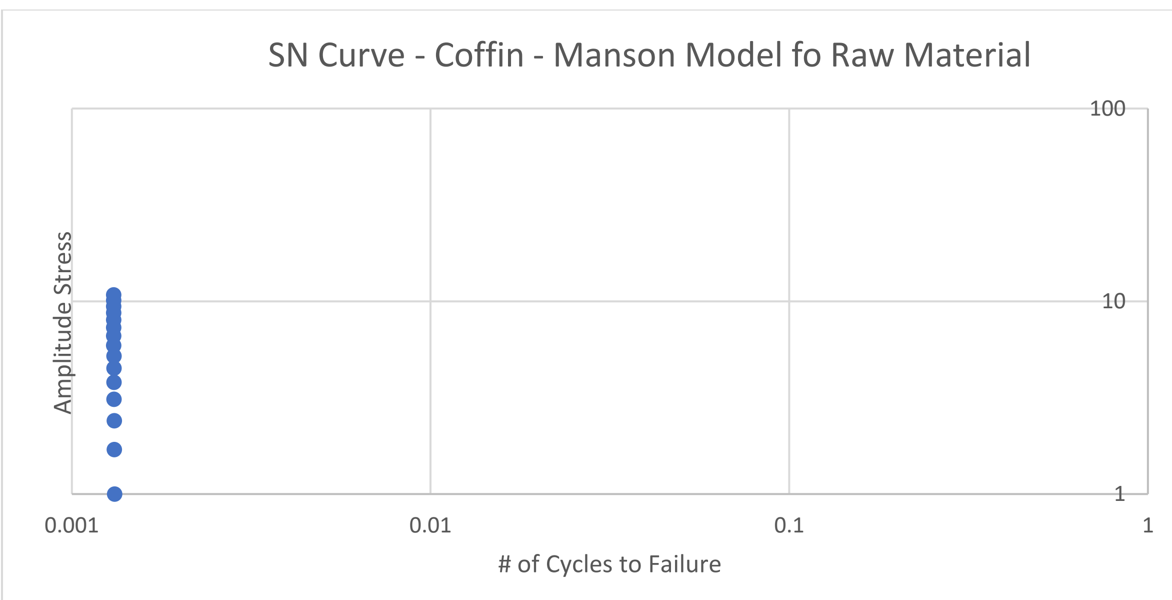


Figure 13:SN Curve based on Coffin-Manson Model for Raw Material

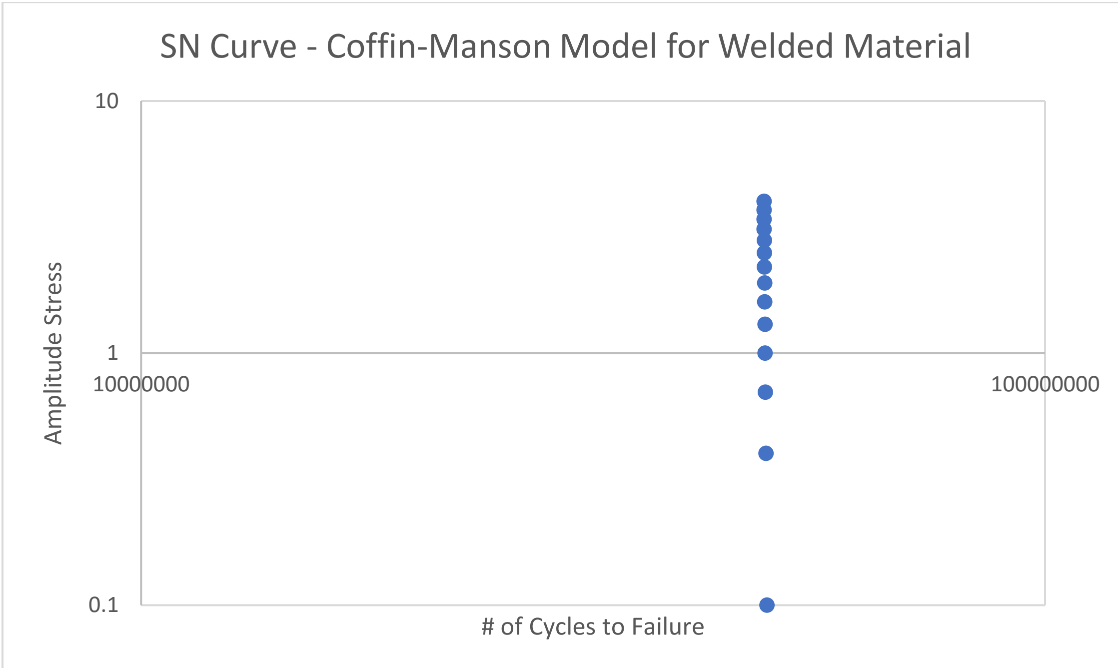


Figure 14: SN Curve based on Coffin-Manson Model for Welded Material

We need to keep in mind that this process was done for both the raw material and the welded material, as seen in *Figure 14*: SN Curve based on Coffin-Manson Model for Welded Material.

It's important to note that the Coffin-Manson model is typically used for low-cycle fatigue analysis, where the number of cycles to failure is relatively small. For high-cycle fatigue analysis, the Basquin model or other fatigue models may be more appropriate.

5.5.4. Running the Basquin Model

In the Basquin model, we first identified the range for the fatigue strength exponent, b, which was between 0.05 and 0.3. After careful consideration, we decided to use $b = 0.125$. Additionally, we made an assumption that the estimated number of cycles to failure would be 10,000. By using these two values, we were able to calculate the value for C using Equation 8: Fatigue Strength Coefficient BM.

Once we had all of our values, we were able to run the number of cycles for a specific range of pregiven stresses based on the known stresses we got from testing the maximum forces acting on the suit from specific known actions done by the user, such as bending and reaching up.

To predict the lifespan of a fabric based on the number of cycles it can withstand under fatigue, a number of steps need to be taken. Firstly, the fatigue strength coefficient (C) and the fatigue strength exponent (b) for the fabric material must be determined. Next, a stress amplitude range that is relevant to the fabric's intended application should be chosen, and the corresponding number of cycles to failure (N) can be calculated using the Basquin model equation. This equation uses the stress amplitude (S) as an input parameter. Once the number of cycles to failure has been calculated, it should be plotted against the stress amplitude on a log-log scale to create a Basquin plot. The range of stress amplitudes and number of cycles to failure that are relevant for the fabric's intended application should be identified. Finally, the predicted number of cycles to failure can be plotted against stress amplitude on a log-log scale using Excel to create a prediction curve, as seen in *Figure 15*: SN Curve based on the Basquin Model for Raw Material and *Figure 16*: SN Curve based on the Basquin Model for Welded Material.

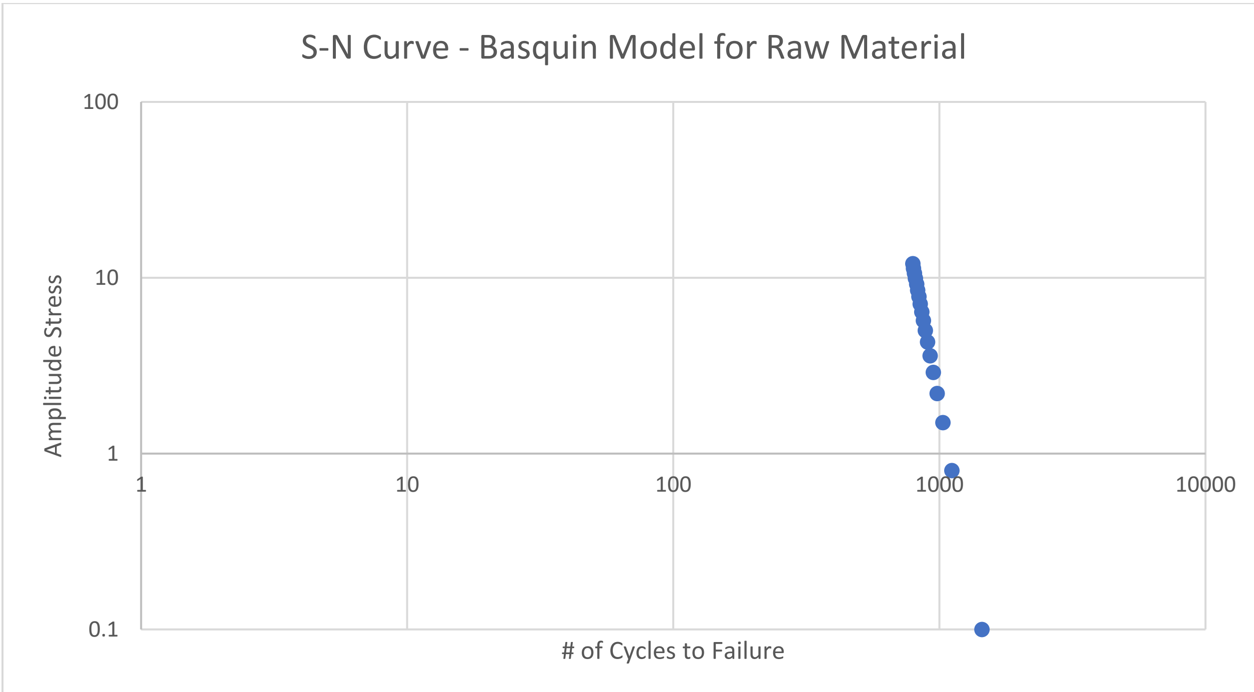


Figure 15: SN Curve based on the Basquin Model for Raw Material

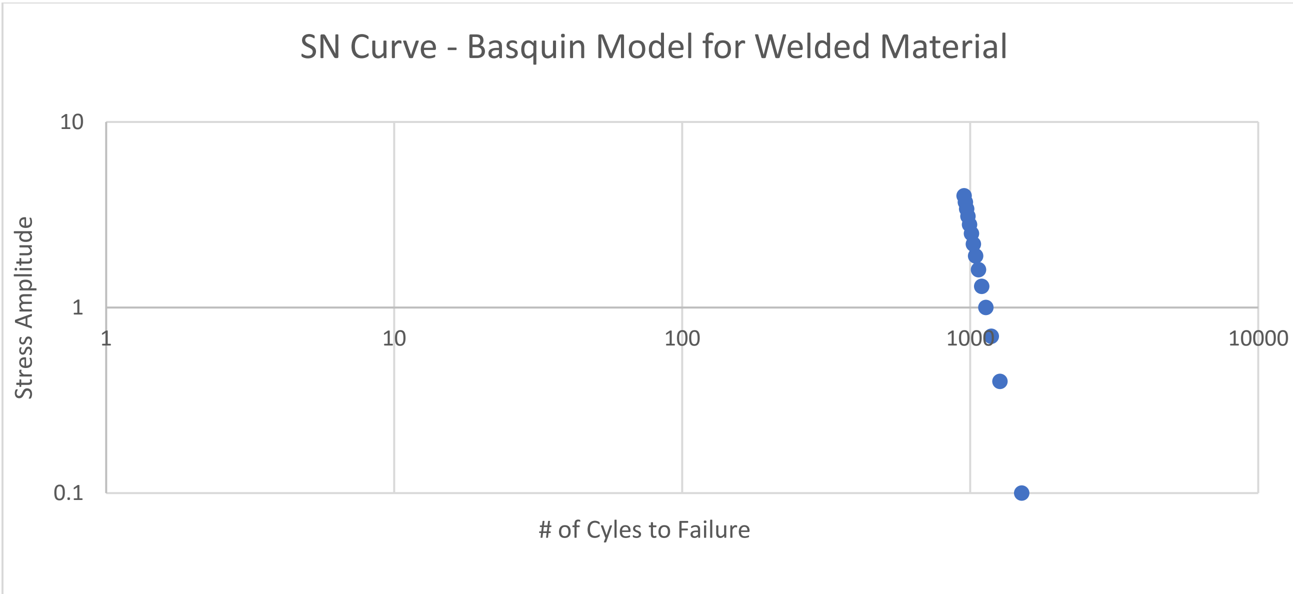


Figure 16: SN Curve based on the Basquin Model for Welded Material

5.5.5. Finalizing the SN Curve

Once we had both model's with their SN curves plotted, we have to plot them both in the same graph as seen in *Figure 17*: SN Curve for Raw Material and *Figure 18*: SN Curve for Welded Material. By doing this we are enduring we get both the elastic and plastic life prediction into one, as we are treating our material as an elastomer, from here we take the SN curve from the intersection point and up. When we tried to do this with our curves, we couldn't do it, as they didn't intersect, which was an issue. After further examining, we decided to go with the Basquin model's SN curve. By doing this our SN curve is only taking into account the elastic life of the material.

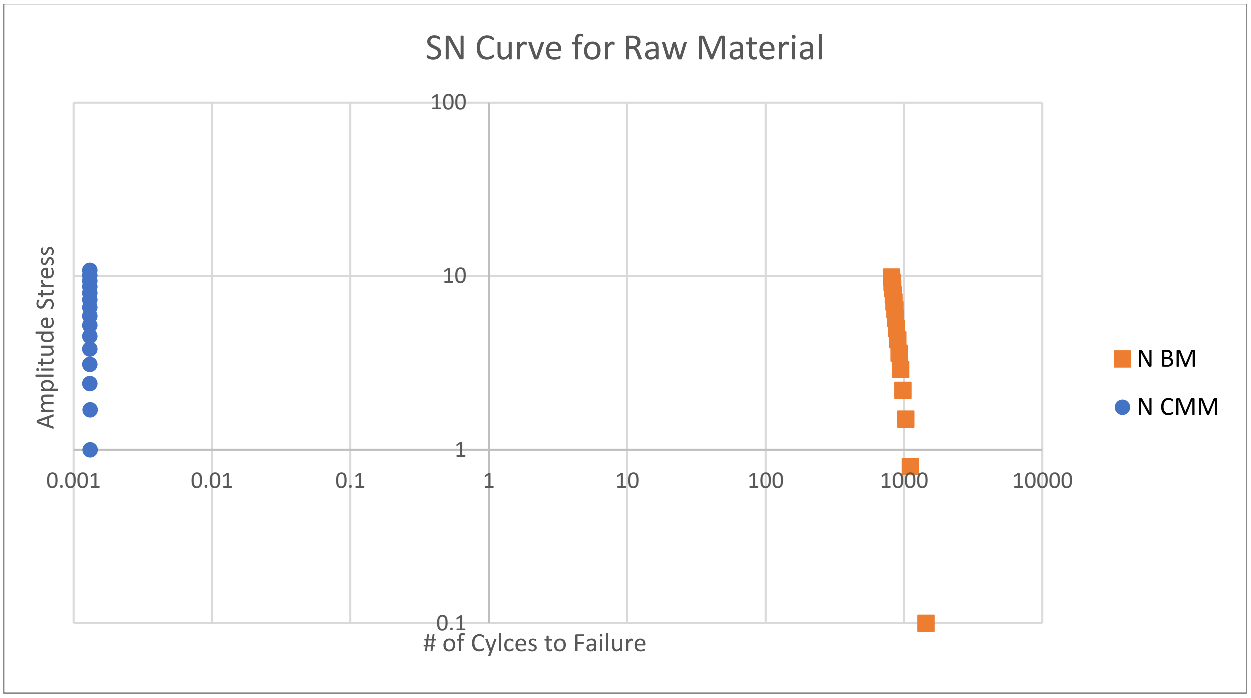


Figure 17: SN Curve for Raw Material

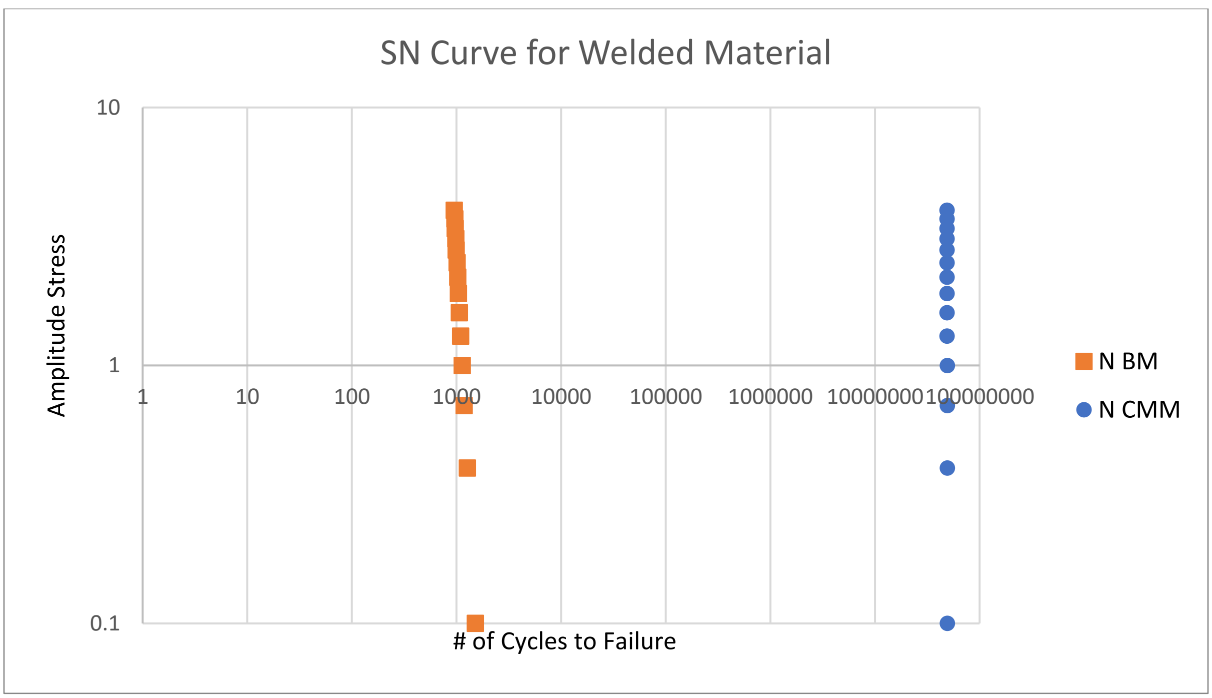


Figure 18: SN Curve for Welded Material

5.5.6. Running the Fatigue Simulation on SolidWorks

In order to simulate the condition under which fabrics are tested for fatigue, we ran a SolidWorks simulation. We created a sample, as seen in Appendix C. From here we subjected the sample to the known maximum stress we found on the suit. We did a static analysis as seen in Appendix D, using the materials properties we had calculated based on our previous tensile testing. We proceeded to start the fatigue simulation by adding the SN curve based on the Basquin Model, as seen in *Figure 16*: SN Curve based on the Basquin Model for Welded Material. We added the events, in order for it to be zero-based and then we proceeded with running the simulation, which can be seen in Appendix E.

5.6. Bio Suit Data Acquisition Method

The Biomedical suits used at Texas Biomedical Research Institute are decommissioned once a technician determines whether the suit is reparable or irreparable. The decommissioning of a biomedical suit is determined by the number of breaches in the suit as well as the size and location of the breaches seen on the suit. The life of a biomedical suit will be defined by the duration of time from the date of first usage until the time of decommission. The problem that Texas Biomedical Research Institute was facing was that the life of the biomedical suits being used in the BSL-4 lab were failing in a shorter amount of time than expected. To understand the life of these suits better, Texas BioMed shared valuable information that could help us calculate the time that a suit could potentially last. This information was found in the sign-sheets used by the lab staff to account for the times when personnel would enter the lab. The sign-in sheets are ordinary pieces of 8x11 with a table printed and a pencil to fill in the fields. The sign-in sheets are continuously used throughout the year and are a good indicator of how much time a suit was in the lab. The sign-in sheet contained Name, Suit Number, Time in, Time out, Description, Radio, Escort, and a confirmed PE checklist field. The sign-in sheets for the years 2019 and 2020 were provided by Texas BioMed in the form of PDF files sent through email.

Many pages were reviewed, and an Excel worksheet was made in which the following fields could be transferred by manual data entry: Time in, Time out and Suit Number. About 2,900 rows of data were collected from the sign-in sheets and used to extract useful information. The data acquisition method became an arduous time-consuming task that had various problems. Due to the sign-in sheets being filled in by different handwriting and different pens and pencils the interpretation of entries became difficult and ambiguous. Certain discrepancies were also found, and some words were illegible to the reader. Although there were some problems with this process, the data was collected and cleaned in Excel as best as possible.

The total time that a suit was used for the years 2019 and 2020 was calculated by first compiling all the Time in and Time out fields for a specific Suit Number and listing them side by side. The third column is then the difference between the Time out and the Time In in hours. All the rows calculated are then summed up to obtain the total amount of time the suit was taken into the lab and because you cannot step into the BSL-4 lab without a biomedical suit, we can assume that the suit was being used for that time. The number of instances a suit was used was also found by taking the number of sign-in times per suit. Using this information, we can quantify how long the biomedical suits have been used in the span of 2 years. Having a total time of usage will aid in providing a comparable measurable that can be used for tests such as the fatigue test seen later in this project.

There are many possible reasons why the Bio Safety suits used at Texas Biomedical research institute are failing at an early stage in their intended lives. To begin investigating the average life cycle of the Bio Suits we looked at the sign in sheets used at Texas BioMed. The sign in times of each suit were recorded and compiled for the years 2019 and 2020. All information collected from the sign-in sheets provided by Texas BioMed was recorded on excel. The data was acquired through manual data entry from sign-in sheet to excel. The data was then cleaned by sorting all sign in times by the Suit ID that was provided. It is worth mentioning that the sign-in sheet used also contained names and sign-in times of individuals who did not use a suit because they did not enter the lab but were there for other purposes such as inspecting the suits or other maintenance purposes. The sign-in time was subtracted from the sign-out time for the suits. This method gave us the amount of time spent inside the lab. Every instance spent in the lab for a specific suit was then summed up to acquire the total time it was used for the years 2019 and 2020.

A2 =FILTER('Entry Log'!$C$2:$C$1048576,'Entry Log'!$E$2:$E$1048576=Sheet2!B1,"")

	A	B	C	D	E	F	G	H	I	J	K	L
1		105			125			133			93	
2	10:30	14:40	4:10	8:32	11:42	3:10	9:46	11:57	2:11	9:46	11:57	2:11
3	12:12	14:01	1:49	8:48	11:50	3:02	8:50	12:56	4:06	13:55	15:44	1:49
4	11:20	15:20	4:00	9:00	10:15	1:15	14:01	14:39	0:38	13:48	14:50	1:02
5	10:35	15:48	5:13	12:45	16:38	3:53	8:48	11:40	2:52	8:48	11:40	2:52
6	9:52	15:02	5:10	9:00	11:29	2:29	1:00	1:46	0:46	13:44	14:42	0:58
7	11:12	17:10	5:58	8:48	10:40	1:52	0:50	2:06	1:16	8:25	9:49	1:24
8	10:33	14:41	4:08	16:28	16:30	0:02	13:30	15:37	2:07	12:50	13:52	1:02
9	8:35	12:06	3:31	8:36	12:32	3:56	8:39	10:37	1:58	13:20	14:21	1:01
10	10:40	13:30	2:50	8:54	10:30	1:36	8:43	10:11	1:28	14:04	15:10	1:06
11	10:43	15:55	5:12	12:46	16:47	4:01	12:51	15:00	2:09	13:00	14:03	1:03
12	14:48	15:34	0:46	8:37	13:07	4:30	9:10	10:31	1:21	14:24	15:59	1:35
13	12:26	16:21	3:55	8:08	12:06	3:58	1:00	1:49	0:49	13:00	15:00	2:00
14	11:08	15:46	4:38	9:26	11:36	2:10	12:50	4:49	15:59	7:14	9:16	2:02
15	9:52	13:36	3:44	8:32	10:20	1:48	13:28	16:26	2:58	12:59	14:44	1:45
16	10:50	14:01	3:11	8:19	13:02	4:43	0:53	2:00	1:07	8:17	10:20	2:03
17	15:09	16:38	1:29	8:35	13:53	5:18	23:06	2:32	3:26	8:16	9:21	1:05
18	13:06	15:18	2:12	8:12	12:30	4:18	8:32	12:41	4:09	8:43	10:17	1:34
19	9:59	14:16	4:17	9:39	14:17	4:38	12:45	14:01	1:16	8:35	10:13	1:38
20	10:06	15:10	5:04	8:41	13:23	4:42	18:36	19:15	0:39	13:00	13:21	0:21
21	14:45	17:10	2:25	8:33	12:52	4:19	7:16	8:19	1:03	6:56	9:19	2:23
22	11:35	13:00	1:25	8:24	13:01	4:37	17:10	19:06	1:56	12:59	14:00	1:01
23	9:46	12:10	2:24	10:05	11:21	1:16	0:52	2:49	1:57	7:03	10:04	3:01

Figure 19:Excel Worksheet of data entry for suits

This arduous process to obtain simple data is the reason why having a data collection system would be useful.

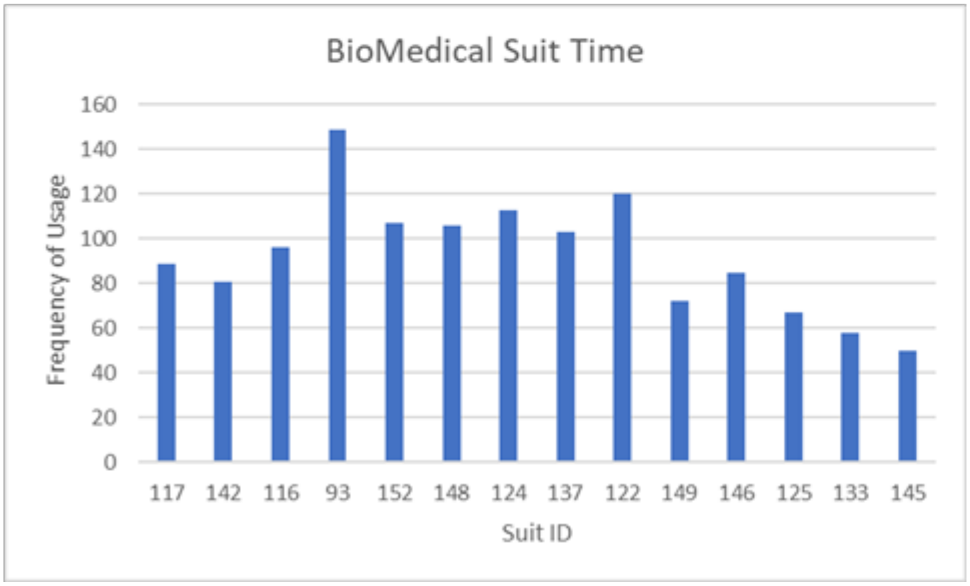


Figure 20: Suit Time- Frequency of Use

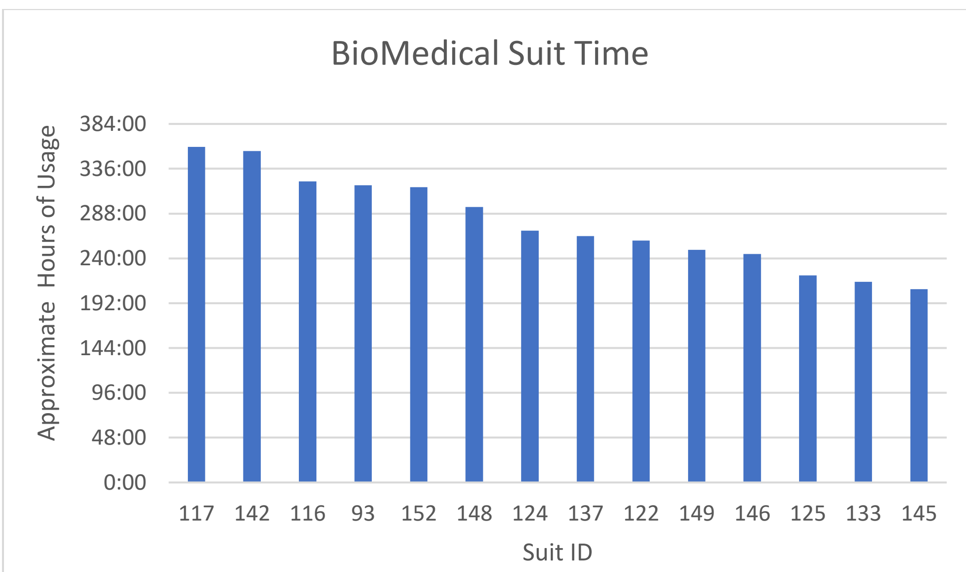


Figure 21: Suit Use- Hours of Use

5.7. Mobile App for Data Acquisition

The Texas BioMed Sign-In App is a data-collection application that displays a user-friendly interface for people who will be entering the labs with a specific lab suit. The people who enter the BSL-4 Lab will be able to sign in and out easily using this app. The use of a mobile app to replace the conventional pencil-paper sign-in method is a beneficial method for all users who are affiliated with the BSL-4 lab entry logging system. This mobile app is planned to be used on an iPad or any other similar device through the Power Apps application. Power Apps (powered by Microsoft) is a user-friendly app designer tool that allows users to create applications with or without existing datasets. The Power Apps application can be installed on any IOS devices and Android Devices. All data that is generated through the Texas BioMed Sign-In App will be stored using a SharePoint list. Using SharePoint is convenient because the data that is generated through the app can be exported to an excel sheet file or a csv (Comma-separated values) file.

As the processes of this project have shown, there is little knowledge on the premature failure of the BSL-4 suits. To learn more about these failures, it is important to quantify how long the average suit will last before being deemed as unsafe and thus decommissioned. The only current method of obtaining this data is to extract the amount of time the suits have been worn from the sign-in sheets that are used when coming into the BSL-4 labs. There are many problems associated with this approach and they come from the difficult process of compiling all the information accurately. The inconsistency in handwritten information makes it difficult to manually input this data into an excel sheet; there is much room for error. Some sign-in sheets could potentially become lost or damaged. Having an app that could collect and organize this data in a neat form, could save much time and worry.

The Texas BioMed Sign-In App will consist of a user-friendly interface that allows the user to easily create a new entry log that contains several pieces of information. First, the Name of the user will be inserted into the text field using the onscreen keyboard or the user also has the option of using a voice command option to say their name so that it generates automatically. Then a pop-up calendar and time scroll down menus will be provided so that the user can input the respective date and time of entry. A Suit ID scroll down menu will be provided so that users can identify and select their suits. Finally, a comments section will be provided for anything that users may want to note.

5.7.1. First Iteration

The initial app development stage begins with creating two separate lists on Microsoft SharePoint. SharePoint makes it easier to connect with Power Apps and allows for data importing and exporting. SharePoint allows the user to work with datasets called lists. The first list created was the Suit Inventory list. This list consists of the following columns, Suit ID, Active, Start Date and End Date. The Suit ID column refers to the identification number used by Texas Biomedical Research Institute to account for each lab suit. Each user is assigned a Suit ID; however, this may be subject to change. The Active column is used to check if the suit is still being used or has been decommissioned. The Start Date will tell you the date of initial suit usage. Concurrently the End Date column is basically the date of decommission of a particular suit. The Suit Inventory list can be edited directly through SharePoint. For example, if a new suit is purchased and needs to be added to the list, the administrator can add a new row. If a suit has recently been deemed unusable, the Active column can be changed to no longer active, and the End Date created as seen in *Figure 22*: SharePoint Suit Inventory List.

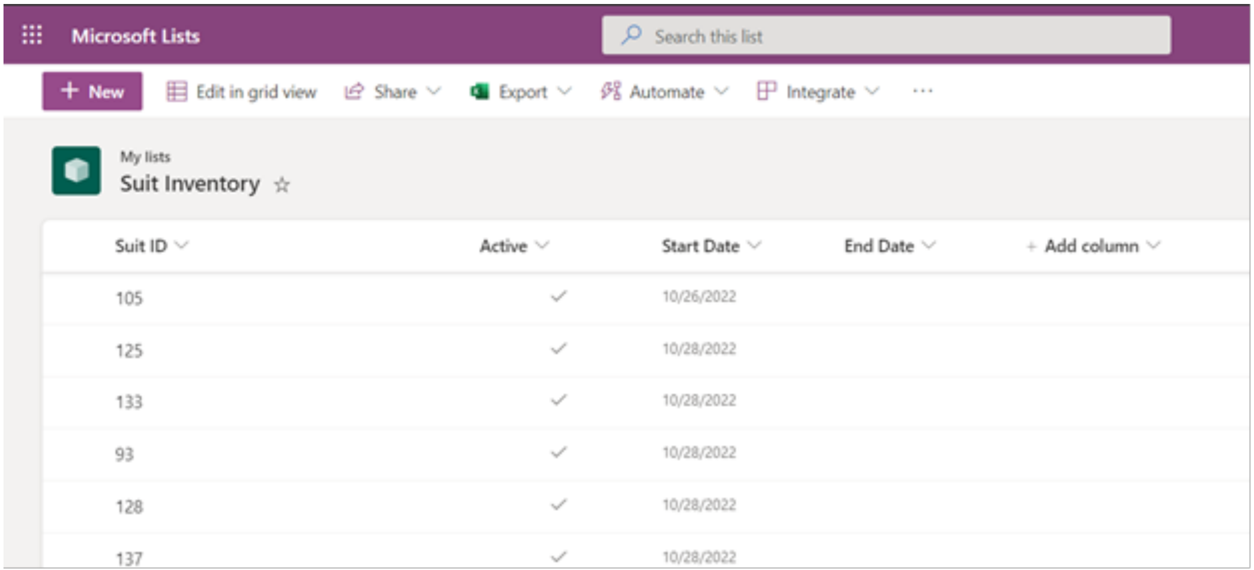


Figure 22: SharePoint Suit Inventory List

The Sign-In Data list will allow the administrator to view the changes made in the app. The Sign-In Data list consists of the following columns Name, Suit ID, Time In, Time Out and Comments. Unlike the Suit Inventory List, the Sign-In Data List extracts data entries made within the app. *Figure 23*: SharePoint Sign-In Data List shows the information of several users that have logged in. Please note that the Time Out column remains blank until the user signs out through the app. Additionally, the administrator may create a new entry log or make edits within the SharePoint Sign-In Data list. The administrator can also view comments made by the users.

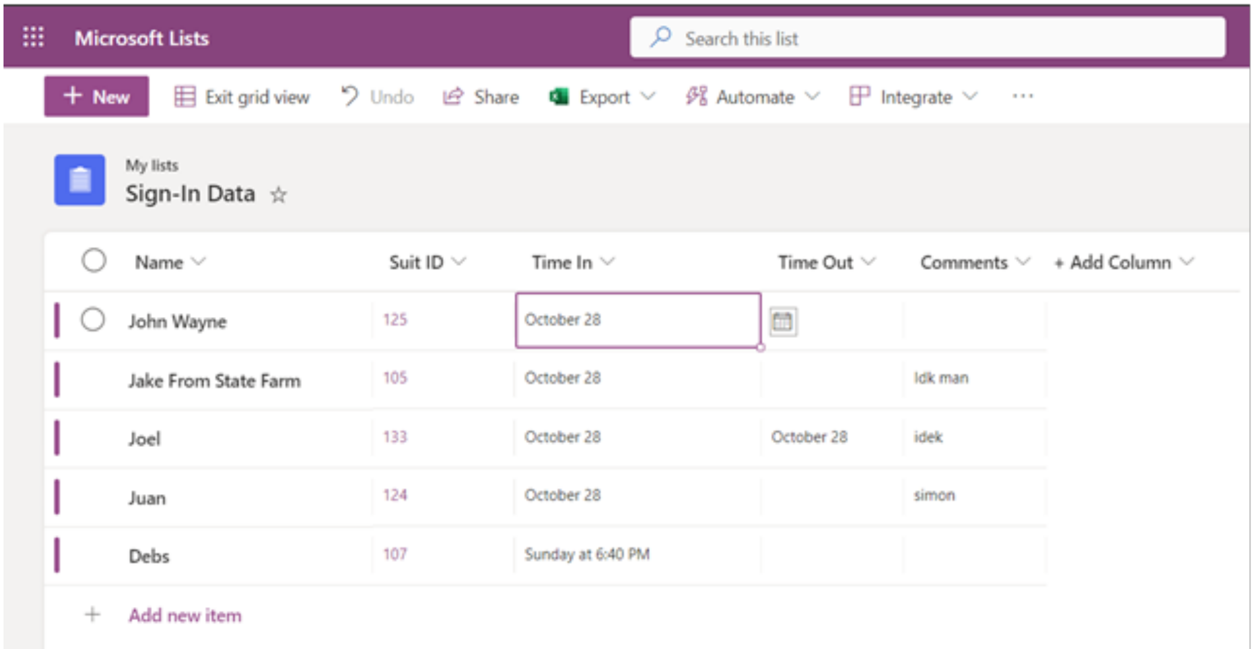


Figure 23: SharePoint Sign-In Data List

The app interface will be easy to use and minimalistic in design to make signing in much quicker. *Figure 24*: Sign-In new entry log screen how's the main screen of the user app interface. This is the screen that the user will initially see. At the Top right the + icon will allow users to add a new entry log.

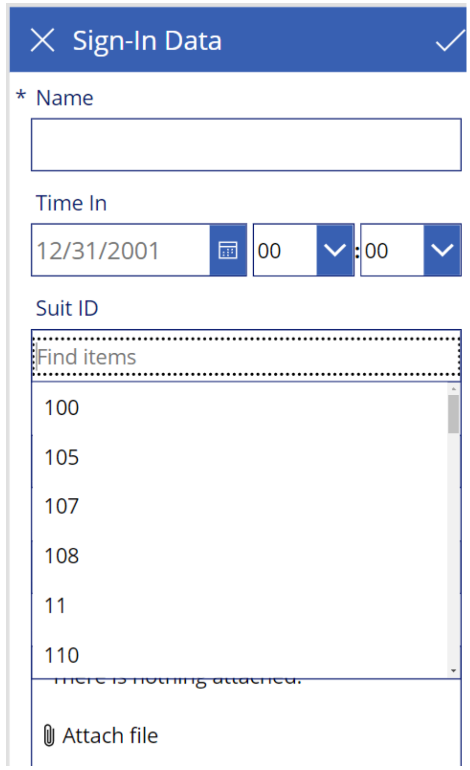


Figure 24: Sign-In new entry log screen

By selecting this icon, the user will be prompted to a different screen where they will be able to enter their information. The name of the user will be entered, and the system's keyboard will be used to write the full name. This is subject to change to accommodate to for a faster sign in time. Time of entry and date inputs are also provided with drop down menus and a calendar feature although the current time and date are automatically acquired upon sign in of the user. In comparison to the original method of signing in, the user will not have to worry about entering the time of entry into the lab nor the date. The information that is added on this screen of the app will be automatically transferred to the Sign-In Data SharePoint list once the check mark icon at the top right of the screen is selected. The Suit ID scroll down menu contains all the items that are currently stored in the Suit Inventory SharePoint list Suit ID column.

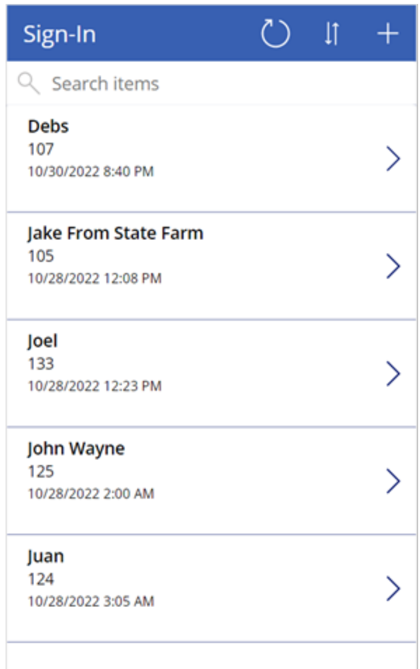


Figure 25: Sign-In entry log gallery

The user will be prompted to the next screen which is a queue of all the entry logs that have been created and are currently keeping record. The items in the queue will not disappear until the user has signed out. Selecting an item in the queue will prompt the user to the detail screen *Figure 26*: Sign-in temporary detailed form. This is subject to change, however for now, the user can observe all the information of the respective entry log user.

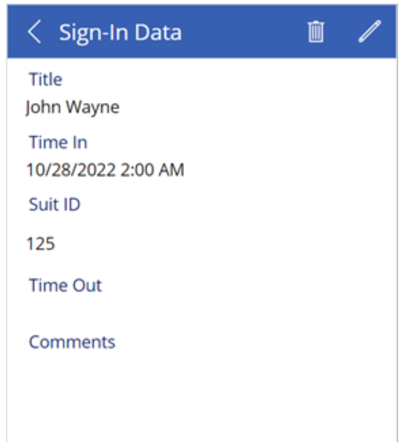


Figure 26: Sign-in temporary detailed form

In the queue, the user can search through the menu by using the search bar at the top of the screen. *Figure 27*: Name Search shows all the user entries with the letter D.

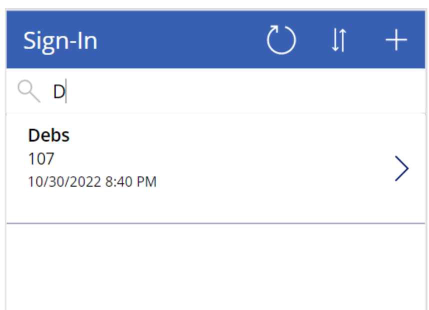


Figure 27: Name Search

The user will be able to select the date and the time of entry, although the plan is to have the present time set as a default so that the user will not have to toggle through the options. This will minimize the time needed to sign in.

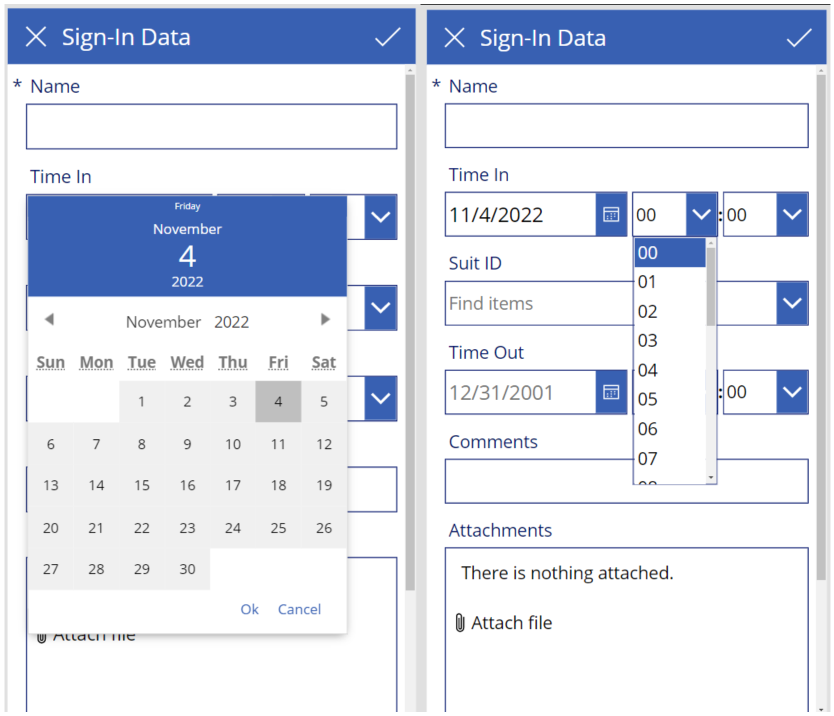


Figure 28: : Date and Time Toggle Features

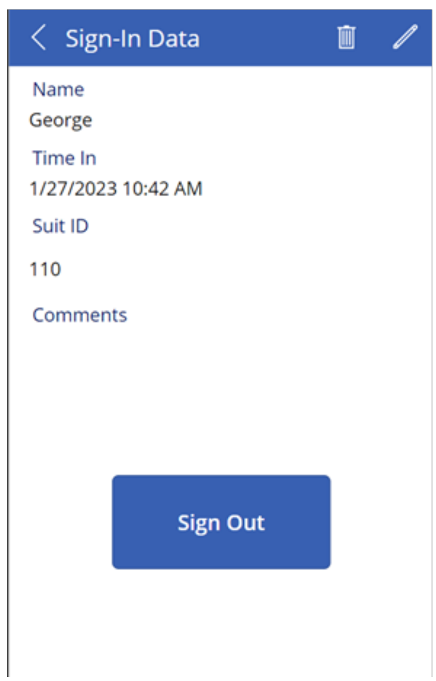


Figure 29: Sign-in Information and Sign-Out Button

5.7.2. Second Iteration

The Texas BioMed Sign-In app in its second iterative phase will contain several different features that will make the app more efficient. There were also several unnecessary features that were removed from the app interface. Overall, the secondary phase will allow for the effective collection of biosafety suit information. With the collection of the sign in and sign out times, the average lifespan of a suit can be explored.

The interface of the BioMed Sign-in app was tailored to make signing in faster. The second iteration of this app included the addition of a Sign Out button that would make signing out easier and more accessible to the user.

The date and time functions of the app interface were changed to accommodate for a faster sign in time by the user. The drop-down hour and minute lists to change the current time were removed to prevent users from being able to change the time of other current users that have signed in. The drop-down calendar was also removed and replaced by a single text box using a function that acquires the current time upon signing in.

These features were removed to protect other users from accidentally editing the time in fields in the wrong way. The time in was previously acquired automatically, therefore the changes made should not affect the user’s ability to sign in promptly. With these changes in the app interface, the user sign in process time should decrease. The user will still be able to edit the sign-in time they choose when they select the edit icon at the top right of the screen.

5.7.3. Testing the App

While testing the app, we found a certain problem with the app interface upon sign in of the user. We noticed that when a certain name was selected on the browser gallery and then the user returned to the gallery from the detail page, the app would automatically go to the detail page of the user that was selected whenever a new sign in was attempted. The new name would still appear in the browser gallery; however, this error was still inconvenient to the process of signing in because it could confuse the user that has just signed in. It is also a risk in that the new user may accidentally sign out the user whose detail page appears automatically.

An analysis of the problem allowed us to discover that the error was rooted in the way that the code was written. After further investigation we found that the reason that the previous user interface kept appearing after a new sign in attempt, was that the back function was being used instead of the navigate function. The Navigate function allows you to choose the destination after the check icon is selected. Once the change in the code was implemented, the app edits were published so that the app on the iPad could be updated. Testing of the app, resulted in the app working properly and no longer having this error.

6. Analysis of Results

The first test conducted was the air-tight test. The purpose of this test was to help us determine the acceptable parameter ranges that would be applicable to our repair method. The following Table 7 shows the results of the different iterations of this test.

Pressure Test			
Sample	1	2	3
330	Pass	Fail	Pass
360	Pass	Fail	Fail
390	Pass	Fail	Fail
420	Fail	Fail	Fail
1000 @ 8%	Pass	Fail	Pass
1000 @ 12%	Fail	Pass	Pass
Continuous Energy			
CE @ 6%	Pass	Pass	Pass

Table 6: Pass or Fail Results for Pressure Test

The first four tests conducted used the energy setting on the welder in which we determined the exact amount of joules the welder would supply to the weld. Additionally, the first four test were welded using the first technique we developed. Essentially the patches were welded using the 1”x1/4” horn that was initially used until our custom horns arrived.

The second iteration of the airtight test deviated slightly from the first. The pressure was decreased, and the joules were increased so that the weld was subjected to a slower increase in temperature for a longer period of time.

For the third iteration of this test, we implemented the new welding technique of overlapping the previous welded section by 50% over the face of the entire patch. The parameter of this weld was also changed to the continuous weld setting. This means that we would determine the amplitude of the weld, time, and pressure.

After we determined the acceptable parameter for the weld by conducting the air-tight test, we wanted to ensure that that the repair would also be capable of withstanding the strain the suit is subjected to under normal use. To help determine this we ran several tensile tests.

The results for the tensile test were recorded and imported into MATLAB to calculate the ultimate strength and yield elongation for each test. The values are listed below in Table 10, Table 11, Table 12, Table 13 for the raw material alone, the Loctite patch method and the varying methods of ultrasonic welding.

Ultimate Strength of Raw Material (N/mm²)						
	Sample 1	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	***Average***
Raw Material	10.4	9.1	11.3	12.9	11.7	11.08

Table 10: Ultimate Strength of Raw Material

Yield Elongation % of Raw Material						
	Sample 1	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	***Average***
Raw Material	23.9442	17.7582	20.0036	23.0826	20.8792	21.13356

Table 11: Yield Elongation % of Raw Material

Ultimate Strength of Patch & Welded Samples (N/mm²)						
	Sample 1	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	***Average***
Weld 1000 J @ 8%	2.1	3.6	2.9	6.5	2.2	3.46
Weld 1000 J @ 12%	1.6	5	2.8	4	3.1	3.3
Continuous Weld	2	7.4	2.8	5.5	6.3	4.8
Loctite Patch	7.8	10.3	7.7	9	9.4	8.84

Table 12: Ultimate Strength of Patch & Welded Sample

Yield Elongation % of Patch & Welded Samples						
	Sample 1	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	***Average***
Weld 1000 J @ 8%	9.5939	24.2831	14.0993	49.6926	26.6985	24.87348
Weld 1000 J @ 12%	3.7888	16.854	13.5202	23.0685	10.0459	13.45548
Continuous Weld	6.8675	26.5847	10.5685	29.7491	19.8618	18.72632
Loctite Patch	26.6697	49.8764	41.4583	47.2353	17.4046	36.52886

Table 13: Yield Elongation of Patch & Welded Sample

The calculations for the stress and strain were also used to create a plot that could put into perspective the mechanical properties of each method. Based on these plots, we could see how the material behaves to tensile stress. Below in *Figure 30*: Loctite Patch and Raw Sample Stress vs Strain Curve, the Raw and Loctite Patch results are plotted together to compare the strength and strain of both test specimens. The Loctite Patch specimens come close in tensile strength to the Raw specimens yet are able to sustain much more strain. The deviations in the Loctite Patch method are indicative of non-uniform specimens having premature failure.

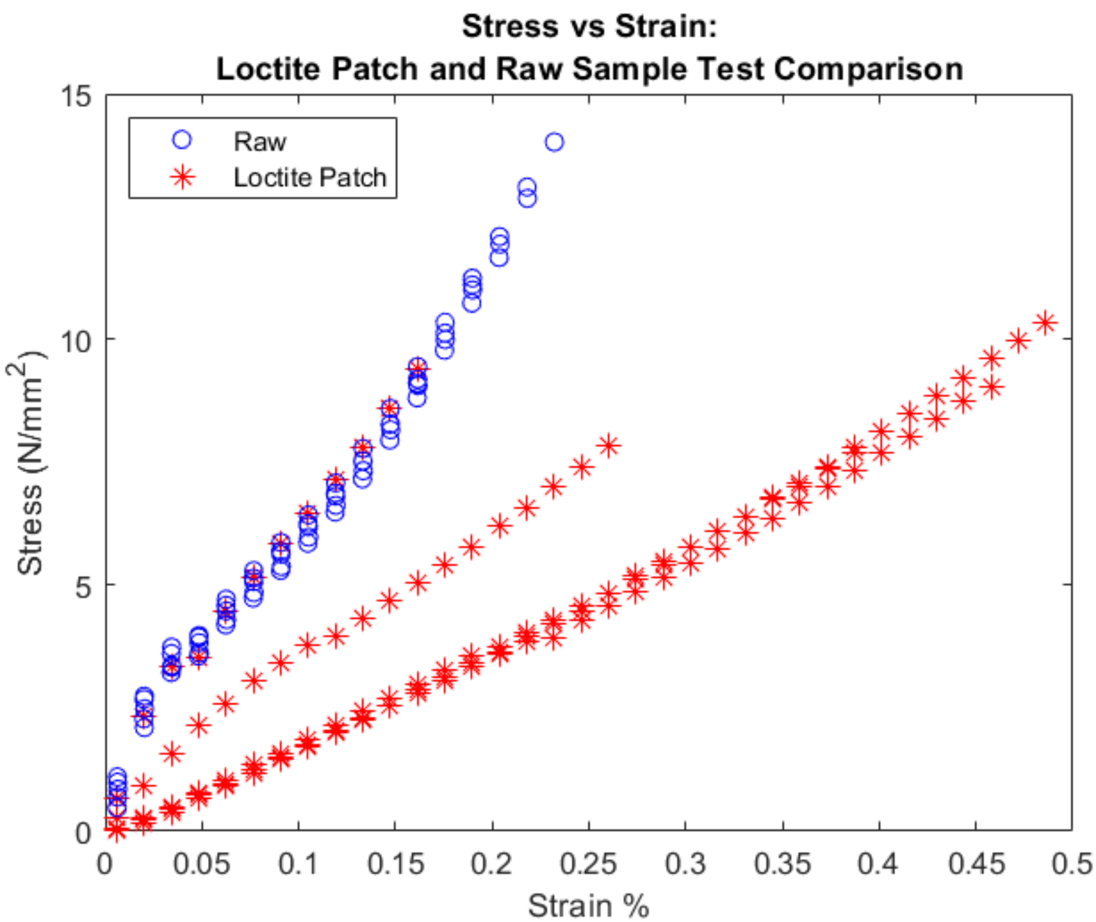


Figure 30: Loctite Patch and Raw Sample Stress vs Strain Curve

The continuous weld strength and strain calculations were plotted below in *Figure 31*: Raw Sample and Continuous Weld Test Stress vs Strain Curve. Based on the plot, certain assumptions can be made regarding the tests that were performed. The first for the continuous weld test would be that uniformity between all specimens was not as easy to achieve yet, it is clear that none of the specimens sustained a significant amount of stress that could suggest outperformance when compared to the Raw specimens or the Loctite Patch specimens. One of the test samples did however sustain a significant amount of strain which could imply that the ultrasonic method when implemented correctly could in fact produce desired results in terms of elasticity.

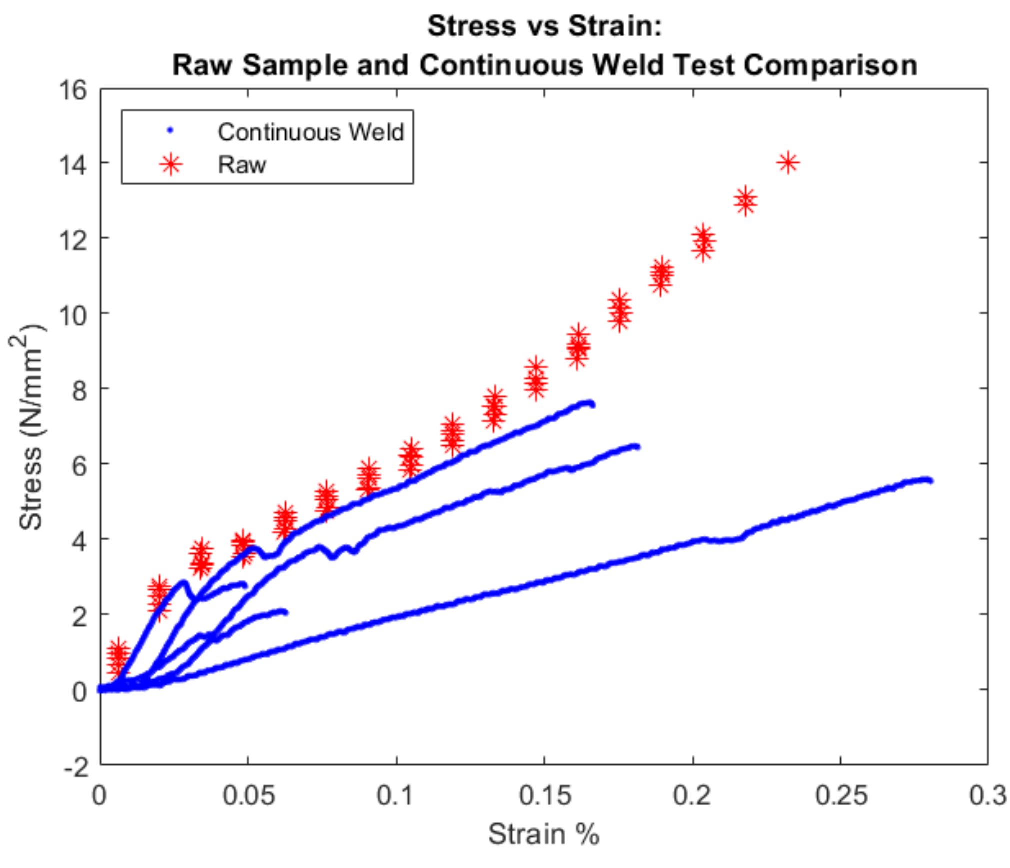


Figure 31: Raw Sample and Continuous Weld Test Stress vs Strain Curve

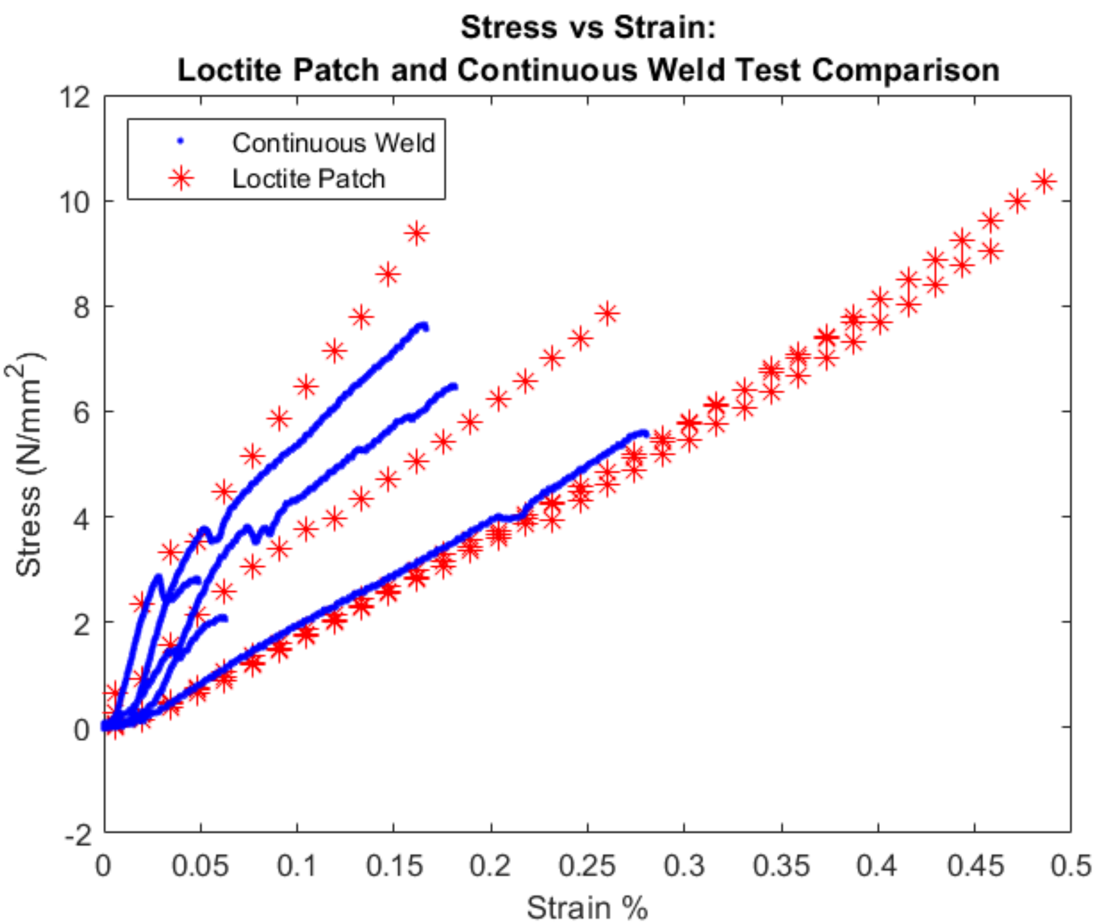


Figure 32: Loctite Patch and Continuous Weld Test Stress vs Strain Curve

In *Figure 32*: Loctite Patch and Continuous Weld Test Stress vs Strain Curve, the results of the tensile test for the Continuous Weld and the Loctite Patch were plotted similarly. The Continuous Weld results greatly varied from each sample. The Loctite Patch results also varied to some degree however there was a trend that started to form between the samples. The results of the Loctite Patch indicate that the material is relatively elastic and can stretch out far beyond what the raw material itself could, to almost 50% of its original length. The Loctite Patch sample does however seem to have less strength compared to the raw material. The Continuous Welded samples had less stress enduring capabilities than the Loctite Patch sample and the raw material.

After completing the tensile test, we had to determine the life of the repair. Using the continuous weld data, we designed a FEA analysis in SolidWorks. Prior to creating a fatigue test in SolidWorks, a static force analysis has or be conducted first. To be safe we used the largest force we measure outlines in section 5.1. Using this analysis, we conducted the fatigue test with a zero-base line reversal cycle. From this FEA analysis it was given that the welded material would be able to withstand approximately 952 cycles before failure**.**

The last test conducted was the chemical test. This test was simply to analyze the effects of the chemical used to decontaminate the suit before and after use.

The results for both the one-sided (1S) and two-sided (2S) test can be seen below in Table 14and Table 15.

Ultimate Strength of Chemical Exposure (N/mm^2)						
	Sample 1	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	***Average***
Chemical Exposure 2S	10.7	10.2	11.6	8.4	10.5	10.28
Chemical Exposure 1S	6.9	6.1	7	7	7.7	6.94

Table 14: Ultimate Strength of Chemical Exposure

Yield Elongation % of Chemical Exposure						
	Sample 1	*Sample 2*	*Sample 3*	*Sample 4*	*Sample 5*	***Average***
Chemical Exposure 2S	65.6818	61.1054	72.4329	49.4386	62.391	62.20994
Chemical Exposure 1S	21.6162	24.6507	21.7833	22.4754	22.4186	22.58884

Table 15: Yield Elongation of Chemical Exposure

In Table 14 the ultimate strength of the two different tests is displayed for the five different samples. The average ultimate strength of the two-sided test was 10.28 N/mm^2. The one-sided test had an average ultimate strength slightly lower at 6.94N/mm^2.

Similarly, the average yield elongation is shown in Table 15 for both iterations of the test. The two-sided test had an astounding 62.2% elongation and the one-sided test had 22.59% elongation.

7. Standards Discussion

The development of an ultrasonic repair method for BSL4 lab suits required the use of several standards. ASTM-D412 was the first standard utilized, which was established by the American Society for Testing and Materials to determine the tensile properties of vulcanized rubbers and thermoplastic elastomers. This standard helped to determine the size and shape of the specimen, the rate at which to test the specimen, and the conditions during the test, which were critical for evaluating the effectiveness of the ultrasonic repair method.

The second standard considered was ISO-6943, which we initially planned to use to help develop our fatigue test. However, after consulting with our professors, it was determined that this method of testing fatigue would not be adequate for our project. Despite not being directly used, considering the standard was important for ensuring the validity of the testing methodology.

The last three standards used were EN1073-1 (Protective clothing against Radioactive Contamination-Ventilated suit), ISO-16603 (resistance of protective clothing materials to penetration by blood and body fluids), and ISO-16604 (resistance of protective clothing materials to penetration by viral aerosols). These standards helped determine the essential qualities of protective clothing and similar materials to what we were working with. This enabled us to identify the necessary qualities that our Ultrasonic Repair method should have, such as its ability to prevent high-consequence pathogens from entering the suit through contact or aerosol particles.

Overall, utilizing these standards helped us to develop an effective ultrasonic repair method for BSL4 lab suits that meets industry standards and regulatory requirements. By following the procedures outlined in these standards, we could ensure that our testing methodology was accurate, and the results obtained were reliable, thereby contributing to the safety of laboratory workers and researchers.

8. Instructional Manual

In order to effectively implement a solution to the reparations of the biosafety suits using ultrasonic welding, an instruction manual was created to aid future operators and technicians in being able to perform the repairs on the biosafety suits. The manual will help the operator to go through the process of operating a handheld ultrasonic welder and provide step-by-step instructions on how to perform ultrasonic welding on Honeywell's level 4 safety lab suits.

The instruction manual relies heavily on the information that was acquired throughout the project. The continuous welding parameters are an example of the information that relates back to the tests and the data that was collected as a result. User experience, extensive research and testing using ultrasonic welding were used to formulate the manual and the information it contains. The instruction manual is essential to producing effective welds that will keep the biosafety suit airtight and ensure that further damage on the suit is not incurred while reparations are being made. This manual will act as a guide on how to use the Branson LPX Handheld Ultrasonic Welder and what measures should be taken prior to the reparations being made on the biosafety suit. The tools and materials necessary are also listed in the manual.

The manual will also warn users of potential hazards and risks that may be present during the ultrasonic welding process. Concurrently, several safety measures are provided in the manual as well as proper disposal of any waste that may be produced. Information on troubleshooting, problem resolution and maintenance are also provided in the instruction manual to provide additional aid to the user. It should be noted that the instruction manual for the ultrasonic welding method is specific to the application outlined in this project which is to repair Honeywell's level 4 safety lab suits. The manual can be found in Appendix F.

9. Conclusion

Our initial trials for the air-tight test proved to be inconsistent and therefore were not viable options to consider for the repair method. It was only until the welding technique changed that we were able to consistently produce and air-tight weld. By overlapping the previous weld by 50% and increasing the time of the weld with lower pressure allowed for the PVC to heat up and melt together before the woven polyester underneath could burn. This helped us determine that we would recommend continuous weld setting with 100% amplitude for one-minute intervals at 6-8% power. By using this parameter and overlapping the welds by 50%, it proved to generate consistent air-tight welds.

Compiling the data from our tensile test allowed us to help determine the material properties of the PVC coated polyester that has been ultrasonically repaired. Using this newly gathered information we could more accurately conduct a simulation of the weld under stress. This enabled us to generate our fatigue analysis. From this FEA we found that the weld would approximately last 952 cycles before failure**.**

If we assume that the weld is subjected to 30 cycles/hour by either bending or stretching, the repair will last 31.73 hours. By using the data TBRI shared with us of the number of hours a suit was used, we calculated the average amount of time that all the suits were used to establish a baseline. It is important to note that many of the suits had less than 100 hours of use over the two year period so we removed those from the average we calculated.

Over the period of two years the average time a suit was used in a lab is approximately 209 hours. Dividing this by 24 months we determined that a suit is likely to be in the lab around 9 hours a month. From this we can conclude that the repair will last 3.5 months under normal conditions.

The chemical test we conducted also showed some intriguing information. Based on the results of the one-sided and two-sided fully submerged tests, several conclusions can be drawn from the plot shown in *Figure 33*: Chemical Tests Comparison Stress vs Strain the data that was collected seems to form a reliable trend for each test. The Two-Sided test results indicate that the fabric becomes more elastic meanwhile maintaining adequate strength. The One-Sided test results showed that the material is slightly more elastic than the raw material itself, yet it has much less strength than the raw material and Two-Sided tests. There is reason to believe that the solution used to disinfect the biosafety suits may be affecting the material causing it to become weaker. There are, however, more factors at play such as cyclic chemical exposure, rinsing and drying of the suits. This assessment only focuses on a maximum condition where the time a suit experiences a decontamination shower is multiplied by the number of instances in the lab, by two for the entry and exit showers and it is then compiled into a single time value. A major point in this experiment is that this is merely an attempt to answer the question of whether or not the PVC coated Polyester Tarpaulin is affected by the solution used in the showers. Although, this approach does not entirely simulate the decontamination showers used in the lab, it offers an adequate method of determining the effect that Micro Chem Plus has on the material.

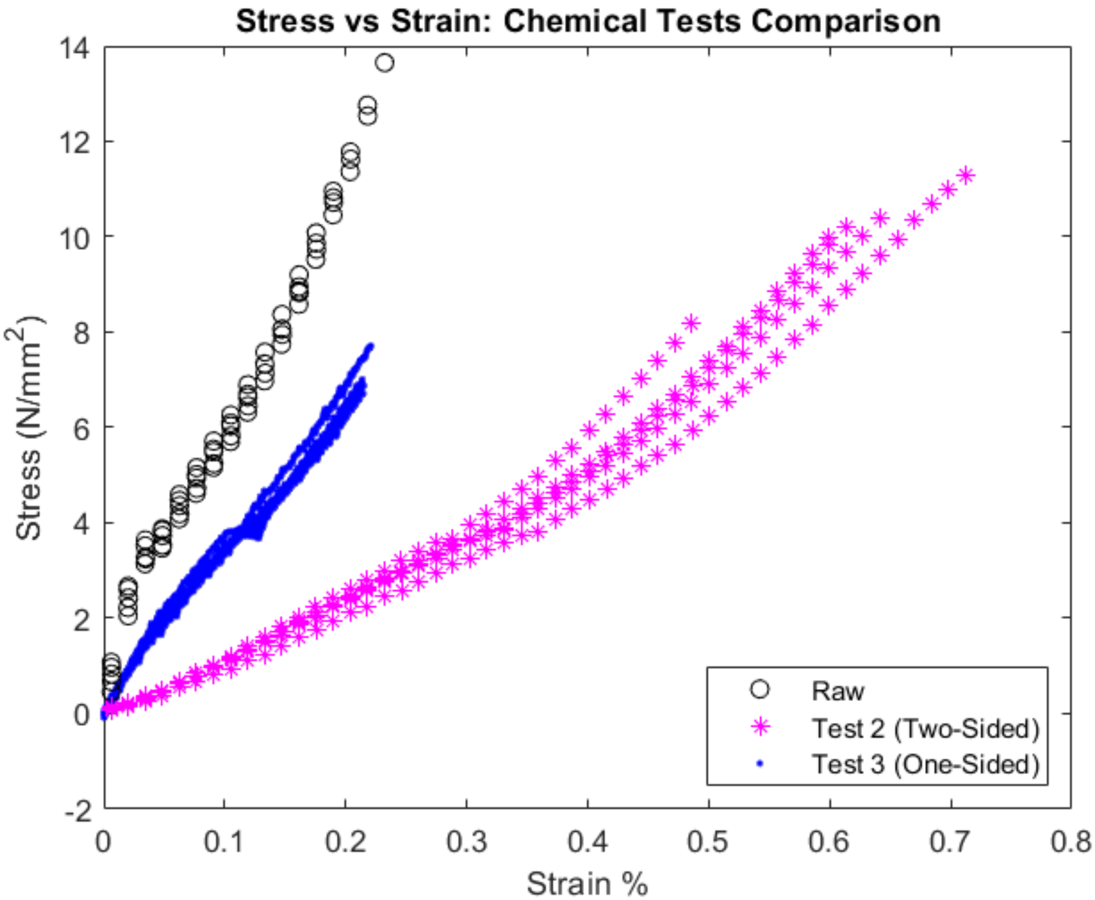


Figure 33: Chemical Tests Comparison Stress vs Strain

10. Recommendation for Further Work

At the conclusion of this project, we found several surprising realizations. The first realization happened after we finished conducting our fatigue analysis. By measuring how much the material of the suit stretched in different areas and comparing those values, we were able to determine the greatest force acting on the suit. Using this force, we conducted a simulated fatigue test in SolidWorks and found that the PVC coated polyester fabric would have a finite life based on the material properties and the S-N curve we developed. Using this same method, we input the material properties of the welded fabric and ran the same fatigue analysis in SolidWorks to find that weld would also have a finite life as well. The life of the repair was less than the life of the raw material, but this was to be expected.

The failure of the suit is also caused by three different factors: abrasion, bending, and chemical fatigue. These are the three areas that will require more testing and analysis to confidently determine how long the ultrasonic repair will last.

Additionally, the material of the suit that we worked with was PVC coated polyester fabric. This project does not account for the clear visor that creates the face shield or the clear plastic that surrounds the rest of the head.

From the data Honeywell provides there is no information on the type of material the face shield is made out of or the other clear plastic. These two materials will have to be analyzed to determine the acceptable parameters that can be used to ultrasonic weld them. Similarly, to our project the welds must also be airtight and capable of withstanding any tensile strain in the localized region of the repair.

There are several points on the suit where all three of the different materials connect forming a corner and around the base of the face mask the clear plastic visor overlaps the PVC coated polyester. There are areas commonly develop breaches and have to be repaired. Another analysis will have to be conducted in order to develop the method for repairing these areas.

10.1. Table Design

To effectively implement an ultrasonic welding procedure, a table must be designed to facilitate the ultrasonic welding process. The table should not exceed an area of 12. Due to the availability of materials and relative cost, the table will be 25”x 48”x 1.75” or near the vicinity of these dimensions without exceeding the maximum area. The main table features shall consist of 2 to 3 sliding drawers, 2 butcher block tabletops and durable slip-resistant caster wheels. This may be subject to change due to the design of the ultrasonic welder and the design of the ultrasonic welding process. The height shall also be designed according to ergonomic standards that will be beneficial to the user of the table. In “*Figure 34: Quick Table Sketch”*, we show what our table will look like.

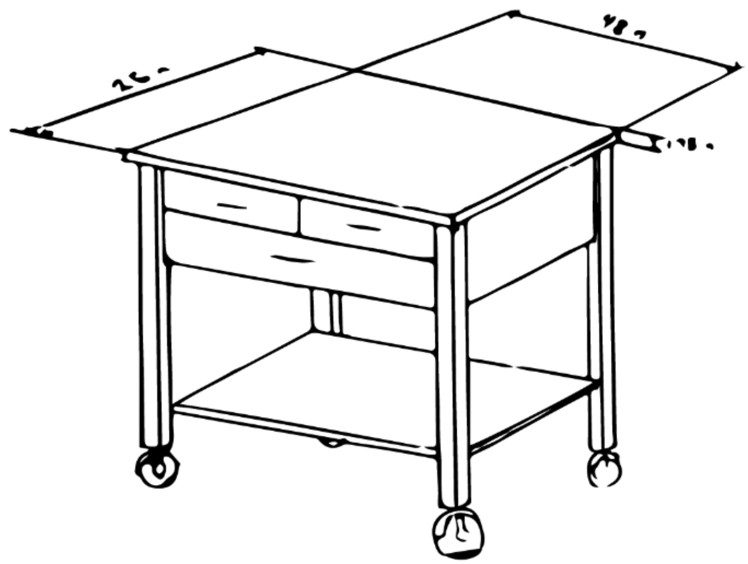


Figure 34: Quick Table Sketch

10.2. Fabrication of Clamping Mechanism

The welding procedure requires that the fabric be laid out flat on the anvil. Having the material sit parallel and flush with the anvil will allow for a uniform weld. With the suit being bulky and heavy a device must be designed to hold the fabric in place. The handheld ultrasonic welding method requires that the operator use one hand to hold the sonotrode and the other to hold the material in place. Having a holding device will keep the operators' hands free of having to keep the fabric straight. The Fabric Fastening Hoop Design consists of two wooden pieces. The design is similar and is derived from the hoops used for embroidery applications. The bottom component will be a uniform profile slab of wood with slots that will fit neodymium magnets 1 inch about its perimeter. The magnets will be fastened to the slab using glue or another method to be decided. The top component will consist of a rectangular wooden hoop that will have a ferrous metal lining about its perimeter. The two components will meet with the fabric in between and be attracted magnetically. The magnetic force will be strong enough to clamp and hold the fabric in place. The anvil will fit through the upper hoop with the fabric in between. *Figure 36*: Anvil Holding Idea clearly depicts the way this system will work.

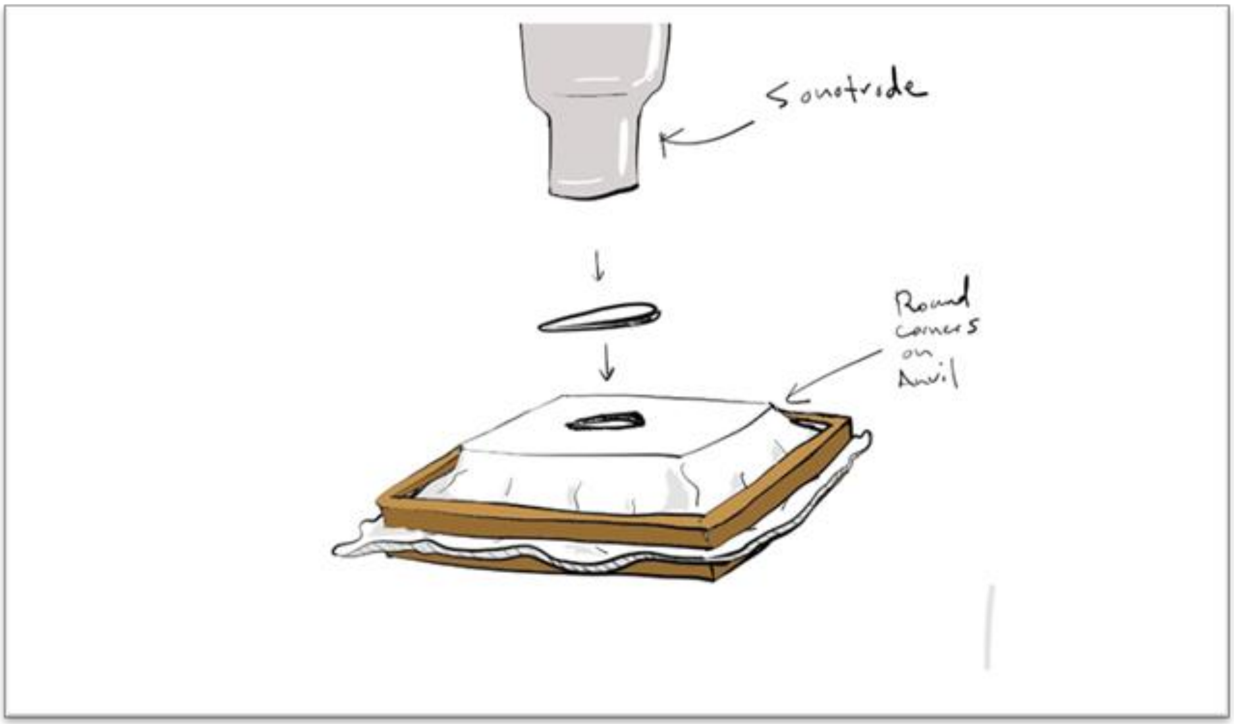


Figure 35: Fabric Fastening Hoop Design

Fabrication of this device is feasible as the materials used are inexpensive and readily available. The shape of the device is also simple and can be fabricated easily.

With a fabric fastening device, the need for a fixture to support it becomes apparent. *Figure 35*: Fabric Fastening Hoop Design is a rough sketch of an idea for an apparatus that can hold the fabric fastening device. The apparatus consists of a clamping mechanism that can be used to clamp the apparatus anywhere around the perimeter of the tabletop. One disadvantage of using this system would be that it must be designed well to hold the any pressure applied as well as the frequency from the ultrasonic welder. A discussion with the team made it clear that it would be far easier to just have the anvil and the hoop fastening device lay flat on the tabletop. This, however, may be subject to change as the ultrasonic welder arrives.

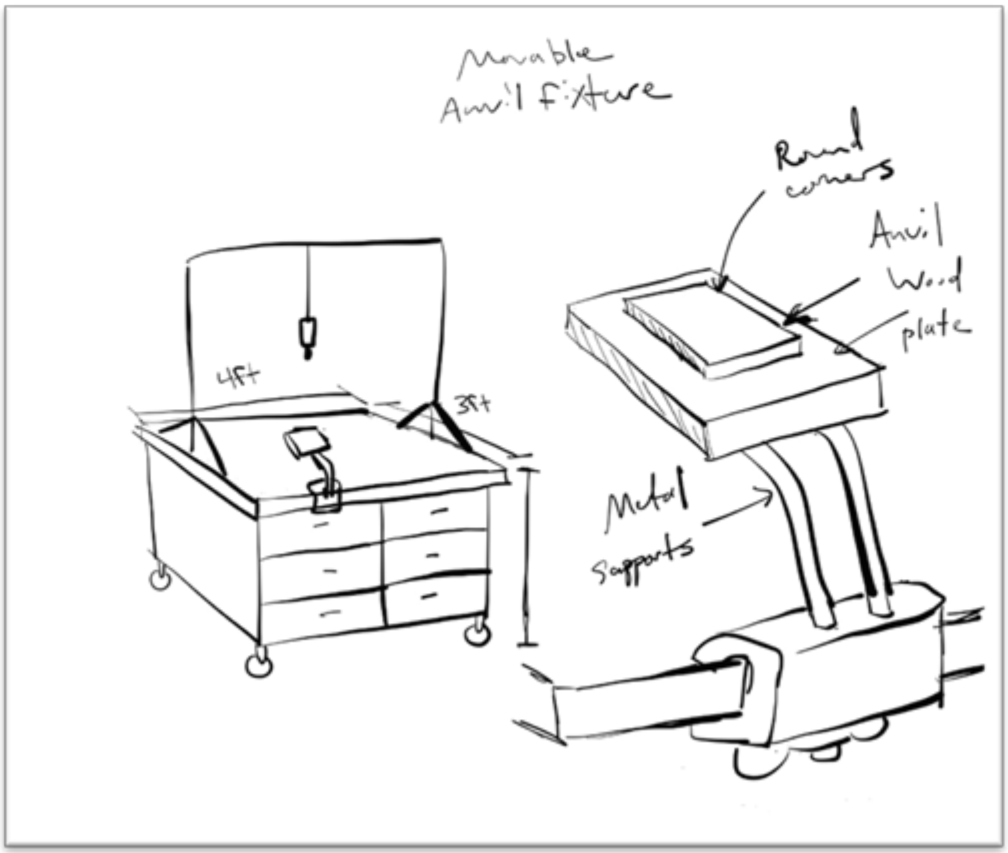


Figure 36: Anvil Holding Idea

10.3. Overhead Ultrasonic Welder Frame Design

The Ultrasonic Welder that is used for this project will be a handheld model. To create an efficient method of welding the bio suits with minimum need for operator skill, a system must be implemented that can perform a quick weld. This design will be used to hang the welder above the welding surface. A retractable tethering device will allow the user to pull the hand welder downwards to perform the weld. This design will make cable organization possible and efficient. The components of the design will consist of T-slot rails, screws, connectors, anchoring brackets and fasteners. The use of pre-manufactured items will allow for easy assembly and reconfiguration if needed. We can see it in *Figure 37*: Overhead Frame.

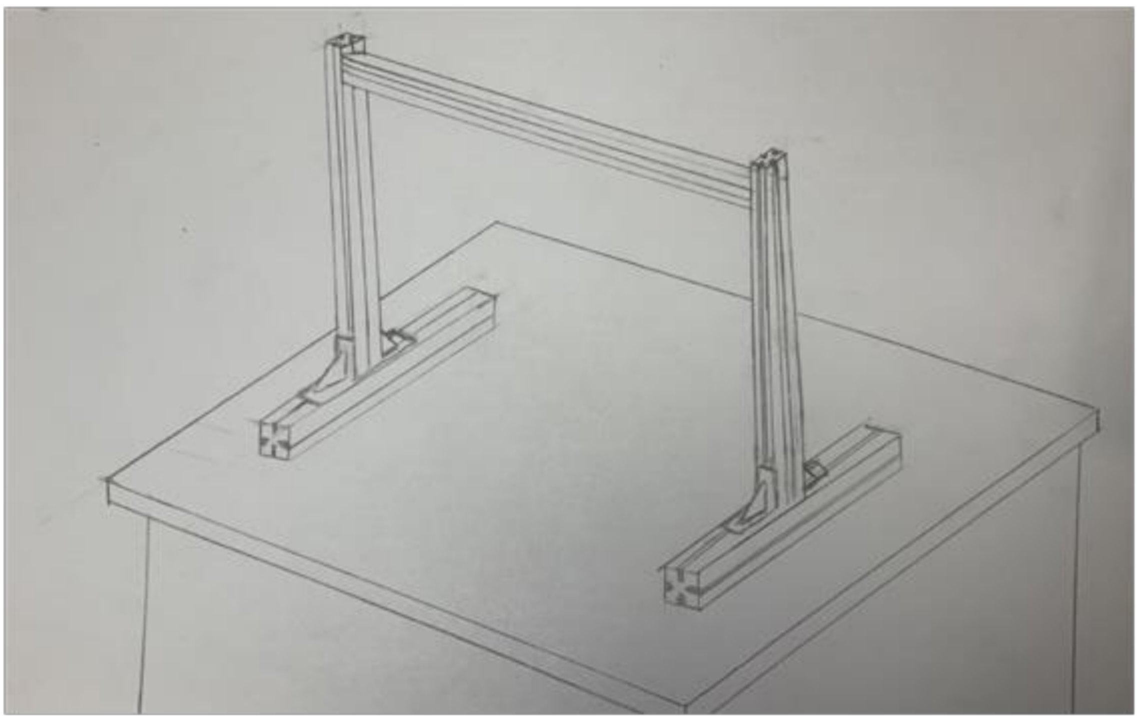


Figure 37: Overhead Frame

10.4. Adaptable Press Design for Handheld Welder

One adaptable press design shall be chosen to automate or facilitate the ultrasonic welding process. Having a press design will allow the ultrasonic welding repair method to be consistent for each weld. To obtain the optimal weld for the PVC coated polyester fabric, the data collected from the tests will be used to create a standard that can be implemented in a standard operating procedure. With a standard operating procedure in place, more control over the life of the weld will be acquired. Additionally, it will be easier to train others if the welding process requires less steps. The optimal weld will most likely depend on several parameters such as pressure, time, and frequency. These parameters are difficult to measure and repeat without a system in place. Figure 10 shows the first design of the press. This design uses an arm that clasps the welder in a fixed position and uses a motor to induce a moment on the arm and bring the welder downwards. Possible limitations of this design include the welder moving out of place and high stress and fatigue on the arm. Also, the design is too simplistic and will not work due to absence of linear motion. The pressure can be measured with the current drawn on the motor. *Figure 38*: Conceptual Design 1*,* show this idea.

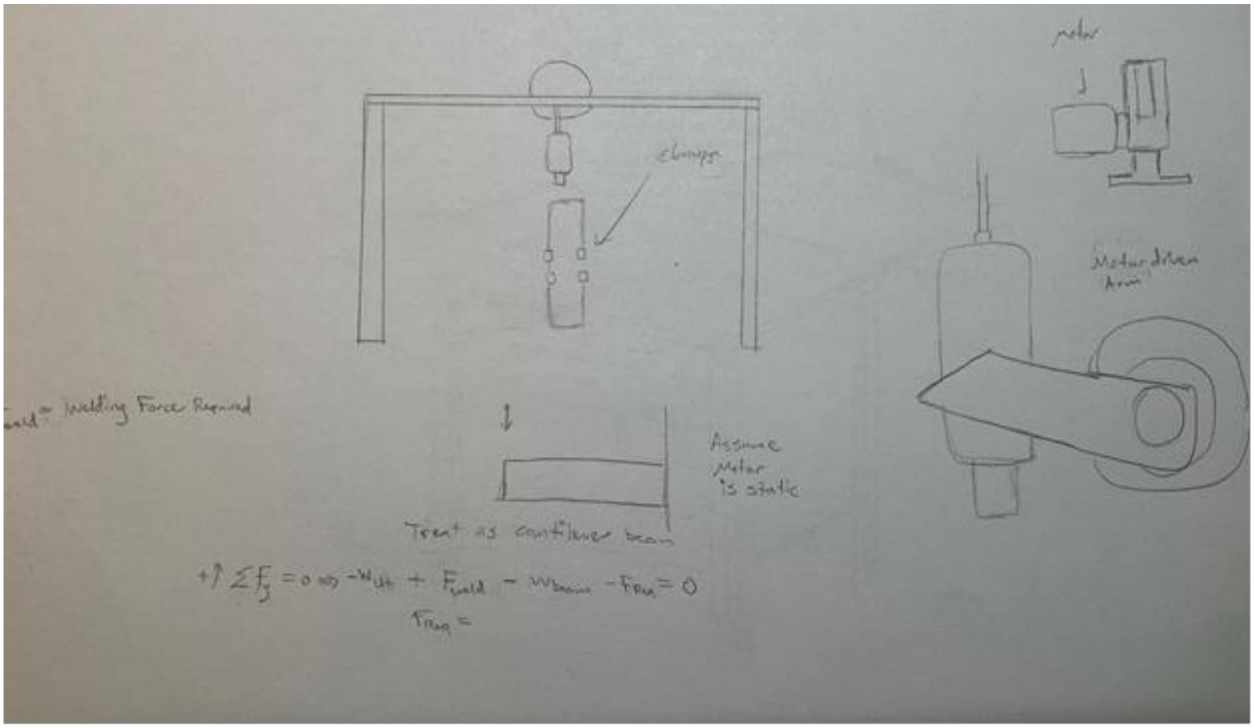


Figure 38: Conceptual Design 1

The second design can be seen in *Figure 39*: Conceptual Design 2 which consists of a rack and pinion system that converts the rotary motion into linear motion. The user can control the depth of the welder, the dwell time and the pressure induced through a feed handle like the feed handles used on a drill press. To measure the pressure of the weld, a scale will be embedded somewhere under the weld surface. One variation of this design would be to remove the feed handle and replace it with a servo motor that can provide the necessary torque and precision to obtain a good weld. Implementing a servo motor would increase the level of automation and would minimize the amount of work the operator would have to do. The steps of the welding process would then be reduced to positioning and fastening the fabric to the anvil, selecting the right settings, and pressing a start button that would perform the welding. A screen may be provided showing the pressure and time of the weld.

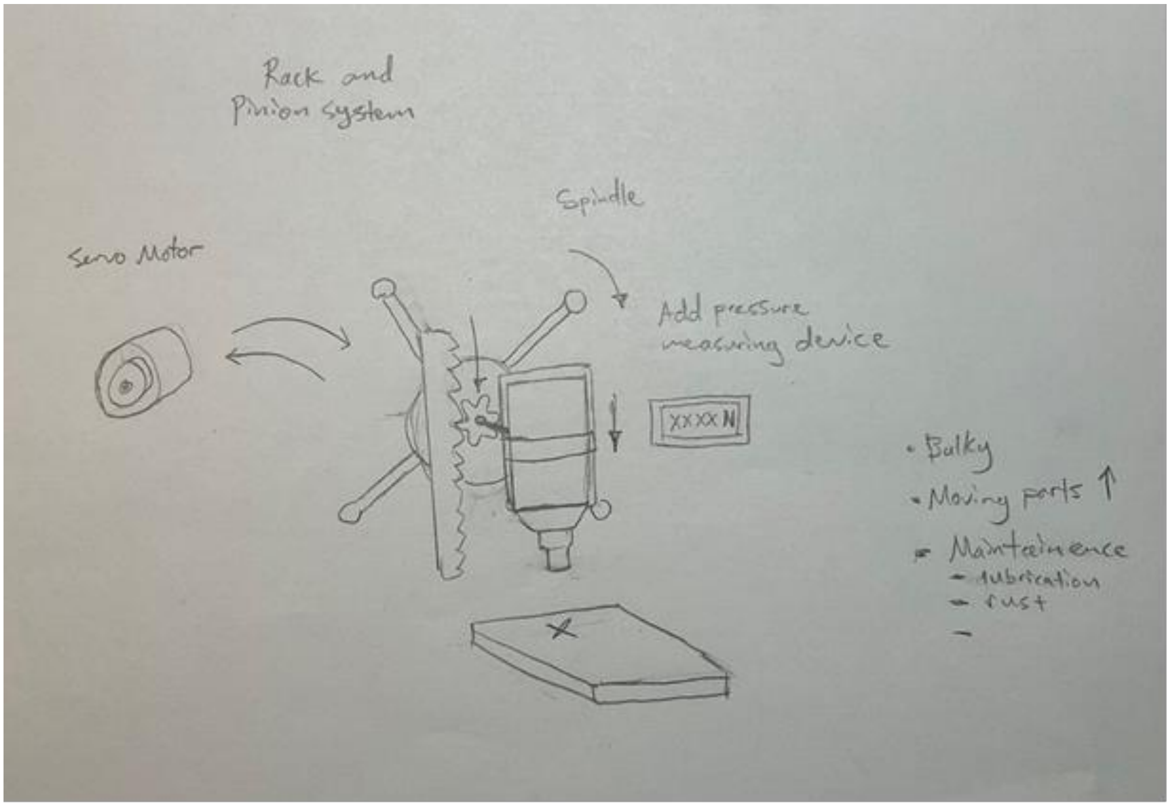


Figure 39: Conceptual Design 2

Most of the designing used in the first iteration of this project did not involve calculations. This is because most of the components of these designs depend on the parameters of the ultrasonic welder. It is difficult to design systems that depend on a single component with unknown specifications. The designs may be subject to change as the ultrasonic welder arrives and testing of the PVC coated polyester fabric begins. The data that is collected will ultimately influence the parameters of the welding process. To create an efficient and optimum welding process, this information is required and until then conceptualization will be what governs the direction of design. More dimensions will be provided in the next iteration of these designs and in turn, calculations. Additionally, 3D Solid works models of these designs will be provided. One last factor and the most important that will dictate these designs are the customer's satisfaction with the first iteration.

11. Business Model

Based on the fatigue simulation that we ran; we were able to roughly quantify the expected life of a suit with the ultrasonic welds. Knowing this value, we then decided to come up with a cost/benefit analysis. Table 16 shows the expected cost of purchasing biosafety suits on a yearly basis.

	Year 0	Year 1	Year 5	Year 10
Cost of Suit	$ -	$ 11,137.50	$ 55,687.50	$ 111,375.00
Cost of Patch Kit	$ -	$ 300.00	$ 1,500.00	$ 3,000.00
Total	$ -	$ 11,437.50	$ 57,187.50	$ 114,375.00

Table 16: Expected Cost of Purchasing BSL4 Suits (Per User)

The values come from taking the estimated cost of purchasing a suit and multiplying it by the number of times they are purchased in a year. According to the Texas Biomedical Research Institute, a new suit is purchased roughly every 4 months although it can vary from 3 to 6 months. The data that was acquired through the sign-in sheets was also used in the calculations for the business model. The average number of hours spent in the lab in a 2-year span was found to be an estimated 209 hours. When this number is divided by the number of months in a 2-year span we find that the average number of hours per month is about 8.7 hours without considering other factors such as scheduling. Using the number of cycles found for ultrasonically welded fabric we then divide this number by the average number of squats per hour a human would perform during work. The result is the life in hours of a suit given these conditions. This value can then be divided by 8.7 to find the number of months it is estimated the fabric will last. The number of months found for the welded material was about 3.64 months. Using this value, we add it to 4 months and divided it by 12 to give us the number of times a suit will be purchased in a year. This result is then multiplied by the cost of a suit to give us the total cost of a suit in a year. The cost of the patch kit was calculated using an estimated number of patches that are purchased by Texas Biomed. Table 17 shows the cost of implementing the ultrasonic welder.

	Year 0	Year 1	Year 5	Year 10
Ultrasonic Welder	$ 6,390.95	$ -	$ -	$ -
Depreciation Expense	$ -	$ 589.09	$ 2,945.00	$ 5,890.90
Cost of Suits Using Ultrasonic Welding	$ -	$ 10,360.47	$ 51,802.33	$ 103,604.65
Total	$ 6,390.95	$ 10,949.56	$ 54,747.33	$ 109,495.55

Table 17: Cost of Implementing New Repair Method (Per User)

A depreciation expense for the ultrasonic welder was included using the straight-line method using an estimated salvage value of $500. The cost analysis is spread out across a span of 10 years.

Average number of hours for suits ($\geq 100\ hours\ of\ usage$)	209
Number of squats per hour	30
Cycles until failure ultrasonic weld	952
Average number of months a new suit is purchased	4
Cost of biosafety suit	$3,712.56

Table 18: Result Life

$$\frac{952\ cycles}{30\ {}^{squats}/_{hour}} = 31.7\ hours$$

$$\frac{209\ hours}{24\ months} = 8.7\ {}^{hours}/_{month}$$

$$\frac{31.7\ hours}{8.7\ {}^{hours}/_{month}} = 3.64\ months$$

$$\frac{12\ {}^{months}/_{year}}{3.64\ months} = 3.29\ suits\ purchased\ a\ year$$

$$\frac{12\ {}^{months}/_{year}}{4\ months} = 3\ suits\ purchased\ a\ year$$

12. SMC Capstone Reflection

12.1. Angela's Reflection

I am immensely grateful to St. Mary's University for shaping me into the person I am today. During my four-year journey, I took a wide range of engineering classes as well as some SMCs, which, at the time, I didn't fully comprehend their importance. As I reflect back, I realize how these classes helped me develop not just technical expertise, but also a well-rounded perspective.

In particular, my senior design project challenged me in ways I never thought possible. There were moments of frustration and exhaustion, but the experience taught me to think creatively and to see problems from multiple angles. I spent countless late nights and early mornings in the lab, working with my team to push through setbacks and achieve our goals. Looking back, I realize how these moments of adversity taught me some of the most valuable lessons in my career.

Throughout my time at StMU, I was fortunate to have supportive professors, who patiently listened to my ideas and helped me navigate challenging situations. I am especially grateful to Dr. McClung and Dr. Ocampo, who were always willing to support me and push me to be my best self.

I had the privilege of working with an incredible team, who not only shared my passion for engineering but also made the journey enjoyable. Whether it was going on dragon hunts or taking silly photoshoots in our suits, we always found a way to have fun together. I am deeply grateful for their unwavering support and friendship, and I wish them all the best in their future endeavors.

As I step out into the world, I am excited for what the future holds for me. I am eager to embrace new challenges and to continue learning, just as I did during my time at St. Mary's University.

I am deeply grateful for everyone who has had a positive impact on my academic journey, but I would like to give a special shoutout to SHPE. This organization provided me with invaluable resources and support that helped me succeed as a student and as a person. I am proud to be a part of such a fantastic community, and I know that I will continue to benefit from its network of mentors and peers throughout my career.

Of course, I wouldn't be where I am today without the unwavering support and sacrifice of my family. Leaving Honduras to pursue my dream of becoming an engineer in the US was a difficult decision, but it was one that my parents supported wholeheartedly. I am forever grateful to them for their love, guidance, and encouragement. As I set out to make my mark in the world, I know that I carry the hopes and dreams of my family and community with me. I am determined to make them proud and to pay it forward by supporting others on their own journeys of growth and discovery.

Today, as a confident and accomplished engineer, I know that I am ready to take on any challenge and succeed in my field. I owe so much of my success to the outstanding education and support I received at St. Mary's University.

12.2. Anthony’s Reflection

My experience at St. Mary's University has provided me with a wealth of knowledge and skills that I believe will serve me well throughout my career. The challenges and projects I have tackled during my time here have helped me develop a solid foundation in engineering, but also in practical problem-solving, teamwork, and communication.

One particular project that stands out to me is my senior design project, where I had the opportunity to work with the Texas Biomedical Research Institute. We were tasked with implementing a new ultrasonic welding repair method for PVC-coated polyester fabric, which required us to learn about material testing standards and ultrasonic welding. It was a fulfilling experience to be able to apply what I had learned in class and contribute to improving the safety of those who wear the suits.

Although I enjoyed the research aspect of the project, I do wish there had been more of a design element involved. Nevertheless, the experience was invaluable in allowing me to develop practical skills and knowledge that will be beneficial in my future career.

In addition to the technical knowledge gained, I am grateful for the cultural and social education I received through my SMCs. St. Mary's is unique in its focus on well-rounded education, and I am proud to have received an education that has made me a more culturally aware and sensitive individual.

As I move on to the next chapter of my life as an engineer, I will carry with me the traditions and education I received from St. Mary's. I am thankful to the faculty and staff who supported and challenged me throughout my journey here, as well as the friends I made who provided me with unwavering support. While I am excited to see what the future holds, I will always look back fondly on my time at St. Mary's University.

12.3. Joel's Reflection

I remember the time when I took dynamics, one of the most difficult classes that I have taken as a mechanical engineering student. The problems that I would study nights and weekends for are still fresh in my memory. Little did I know that the hardship and dedication would shape me into the person that I am today. It is as if I have gone through a long character development stage for these past few years and this project was the peak of the mountain that seemed insurmountable during freshman year.

At the beginning of this project, I was elated to know that I could contribute to something that affected the world in a positive way but as time progressed, I found that being an engineer and coming up with good solutions is not as straightforward as plugging and chugging numbers into the right formula. In the classroom, problems are difficult, yet they become simple if one learns how to dominate the subject. In the world, problems are not as clearly presented and there is much more ambiguity in finding a solution. Almost certainly, there is more than one solution to every problem unlike most of the engineering problems presented in the classroom. Nevertheless, this project has taught me invaluable skills and lessons that go beyond the technical realm. I learned how to work with a team of engineers who often do not agree with everything you say. However, together we learned how to overcome various obstacles such as time availability, difficulty, and uncertainty. We learned skills that I am confident will translate into our careers as we take the next step.

As for me, I look forward to being able to apply what I have learned at St. Mary's University into the real world and reciprocate the generosity that I have received from friends and family who have supported me in my academic journey. I would not be where I am if it were not for my mother who always motivated me to finish school. I know my father would be proud if he saw me today. His lessons and wisdom paved the way for my success, and I will forever be thankful for that. As I enter this new chapter of my life, I reflect on the lessons that I learned as a student and as any normal human being. For all those moments were part of my journey and they will continue to help me in the future.

13. References

[1] Singh, Shivani. "What Is the Right Material for Making Ultrasonic Horns?" *Dukane*, 17 Mar. 2022, https://www.dukane.com/blog/2021/06/28/ultrasonic-welding-horn-material/.

[2] World Class Cleaning & Hygiene Solutions. "MICRO-CHEM PLUS SDS English."

[3] Jongbloed, Bram C P et al. "A Study on Through-the-Thickness Heating in Continuous Ultrasonic Welding of Thermoplastic Composites." Materials (Basel, Switzerland) vol. 14,21 6620. 3 Nov. 2021, doi:10.3390/ma14216620

[4] Janosko, Krisztina, et al. "Safety Precautions and Operating Procedures in an (A)BSL-4 Laboratory: 1. Biosafety Level 4 Suit Laboratory Suite Entry and Exit Procedures." *Journal of Visualized Experiments*, no. 116, 2016, https://doi.org/10.3791/52317.

[5] "Hazmat Protection Levels." *National Environmental Trainers*, https://www.natlenvtrainers.com/blog/article/hazmat-protection-levels.

[6] "BSL 4." *Honeywell*, https://sps.honeywell.com/au/en/products/safety/protective-clothing/ventillated-clothing/bio-safety-level-4-deathly-viruses.

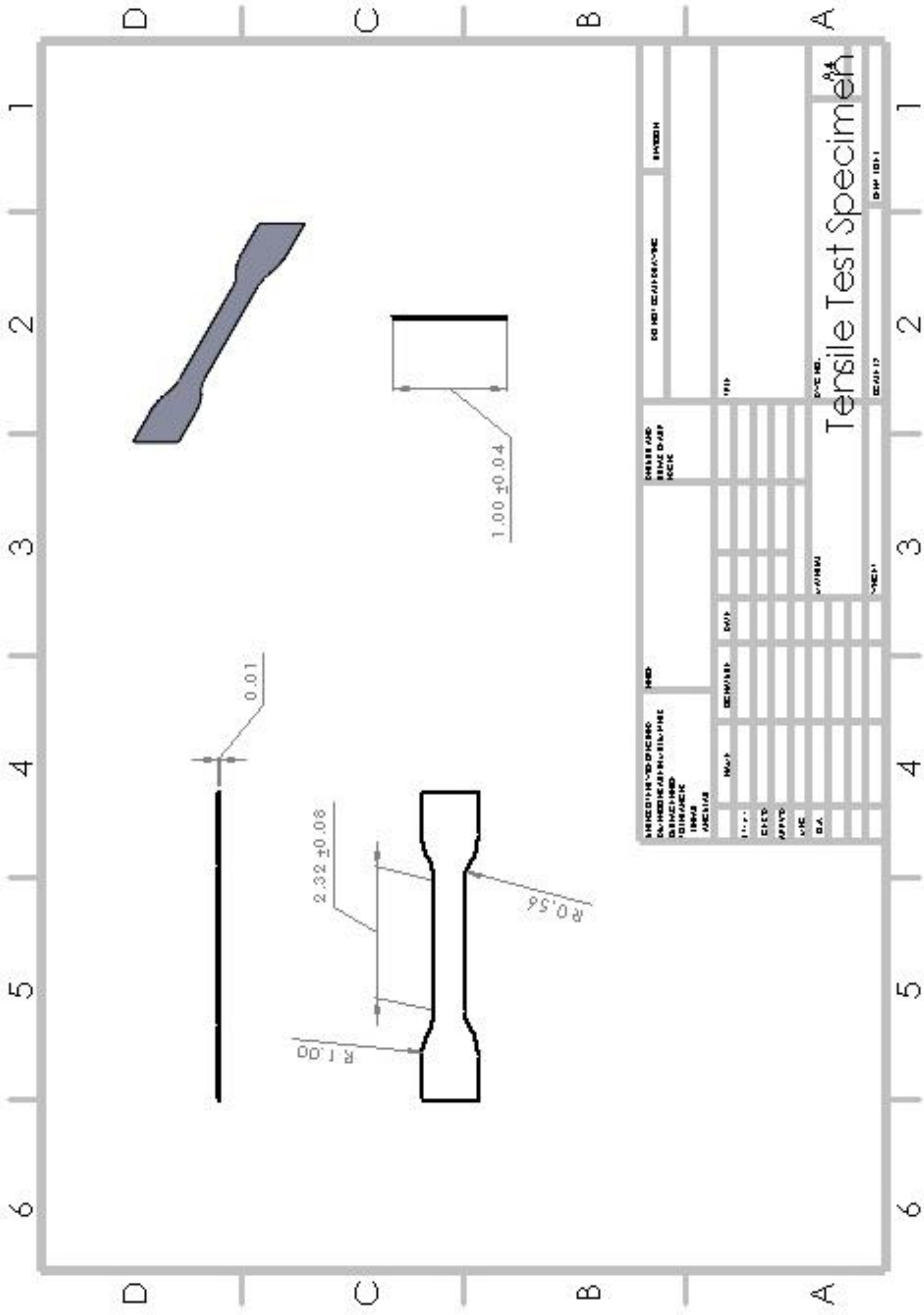
[7] "What Is Ultrasonic Welding? Joining/Reforming Thermoplastics." *Dukane*, 12 Aug. 2022, https://www.dukane.com/plastic-welding-process/what-is-ultrasonic-welding/.

[8] Ira, Stephen. "Applications of Ultrasonic Welding." *HookandLoop.com*, 7 Dec. 2021, https://www.hookandloop.com/blog/ultrasonic-welding.

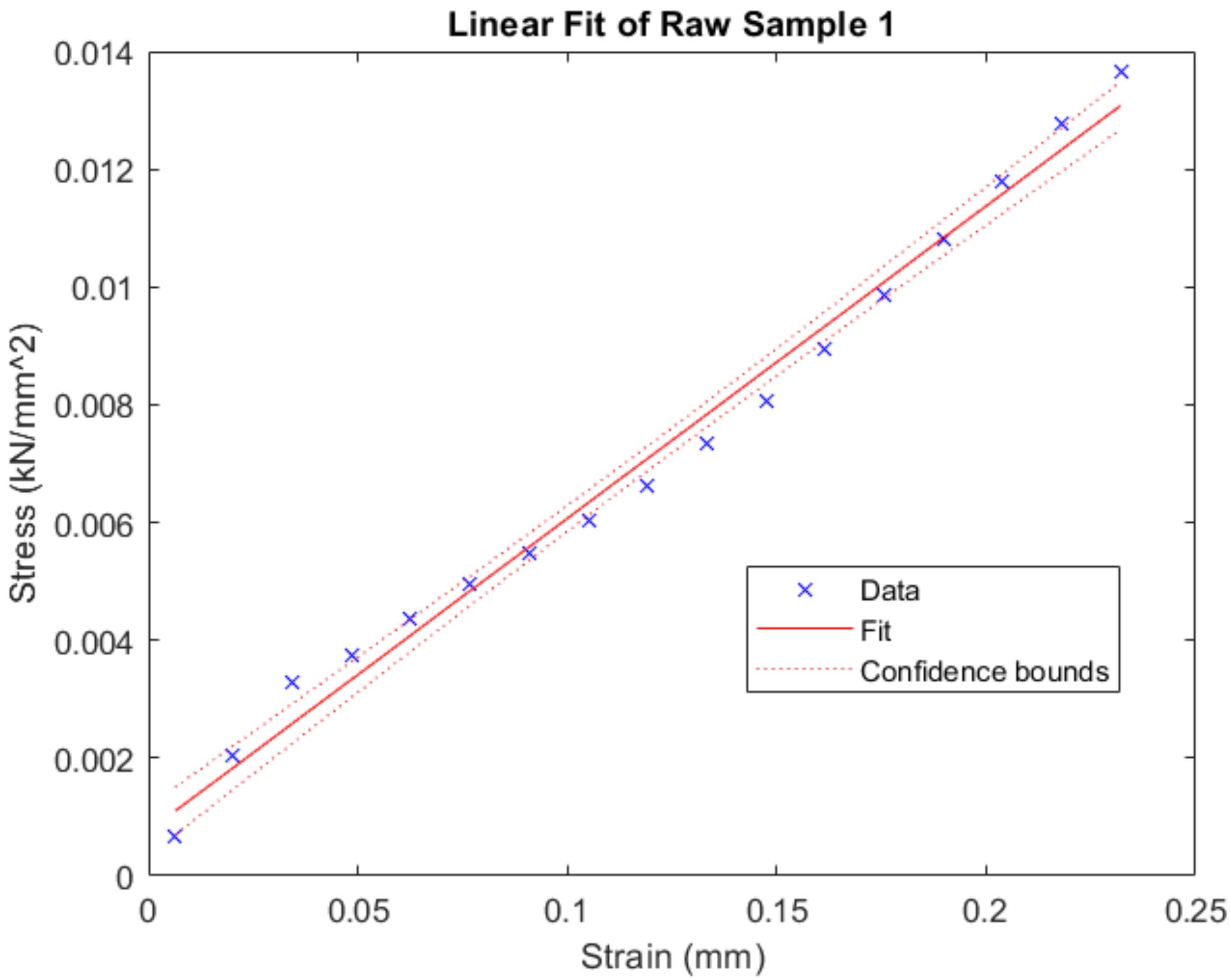
14. Appendices

APPENDIX #	NAME
APPENDIX A	Engineering Drawing D412 Sample
APPENDIX B	Linear Fit for Strain Hardening Exponent
APPENDIX C	Engineering Drawing Fatigue Biaxial Sample
APPENDIX D	Static Analysis – SolidWorks
APPENDIX E	Fatigue Analysis – SolidWorks
APPENDIX F	Manual

Appendix A

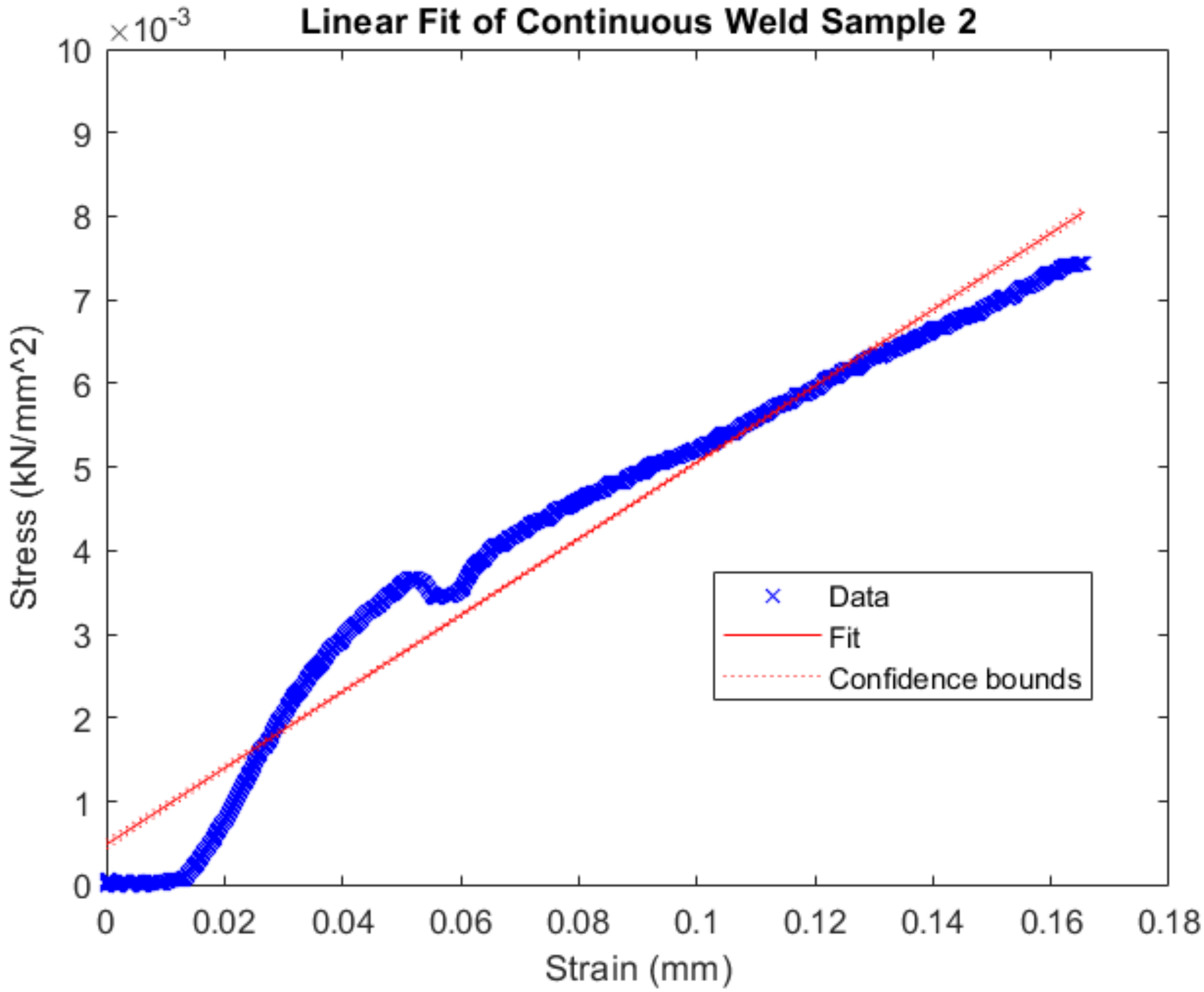


Appendix B


Linear Fit of Raw Sample 1
Stress (kN/mm^2)
Strain (mm)
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
0
0.05
0.1
0.15
0.2
0.25
Data
Fit
Confidence bounds

	Estimate	SE	tStat	pValue
1 (Intercept)	0.0008	0.0002	3.8609	0.0015
2 x1	0.0531	0.0014	36.9637	0.0000

	SumSq	DF	MeanSq	F	pValue
1 Total	2.3152e-04	16	1.4470e-05	NaN	NaN
2 Model	2.2901e-04	1	2.2901e-04	1.3663e+03	3.7779e-16
3 Residual	2.5142e-06	15	1.6761e-07	NaN	NaN

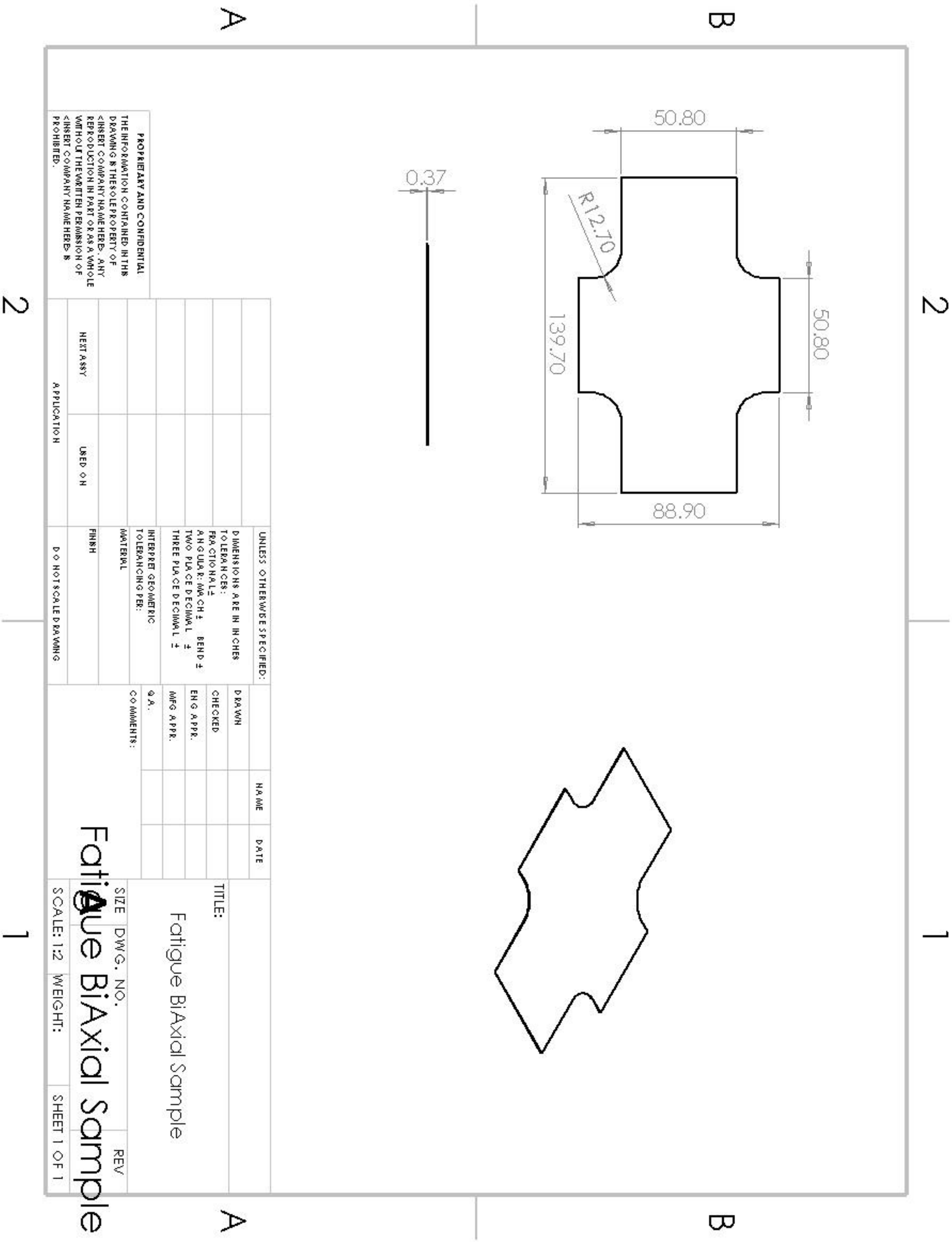


Linear Fit of Continuous Weld Sample 2
×10^-3
Stress (kN/mm^2)
Strain (mm)
Data
Fit
Confidence bounds
0
1
2
3
4
5
6
7
8
9
10
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18

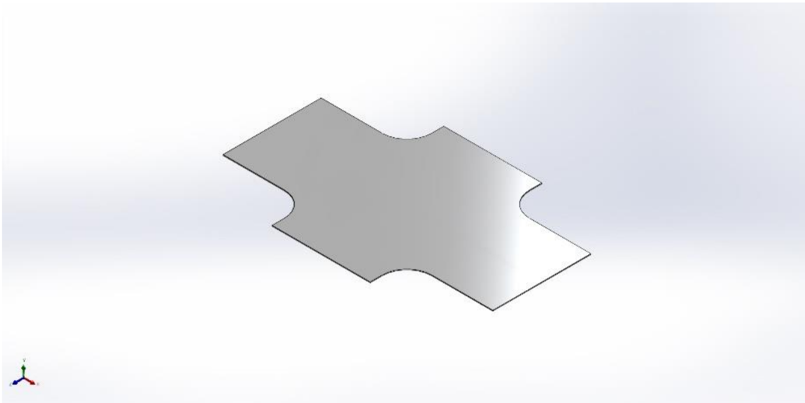
	Estimate	SE	tStat	pValue
1 (Intercept)	0.0005	2.5752e-05	19.0298	5.9116e-71
2 x1	0.0457	2.7566e-04	165.7331	0

	SumSq	DF	MeanSq	F	pValue
1 Total	0.0066	1228	0.0000	NaN	NaN
2 Model	0.0063	1	0.0063	2.7467e+04	0
3 Residual	0.0003	1227	0.0000	NaN	NaN

Appendix C


50.80
0.37
R12.70
139.70
50.80
88.90
PROPRIETARY AND CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
TITLE:
Fatigue BiAxial Sample
SIZE
A
DWG. NO.
Fatigue BiAxial Sample
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1

Appendix D



Static Analysis for Biaxial Sample

Simulation of Fatigue BiAxial Sample

Date: Thursday, April 13, 2023

Designer: Solidworks

Study name: Static 1

Analysis type: Static

Study Properties

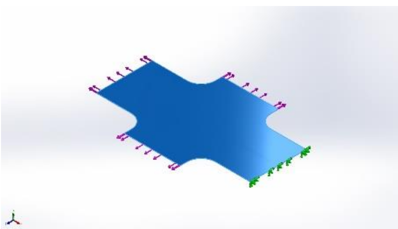
Study name	Static 1
Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	Automatic
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off

Use Adaptive Method:	Off

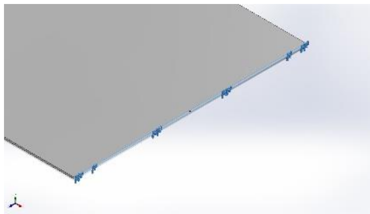
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

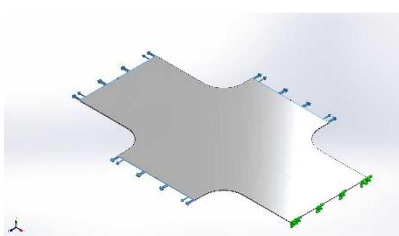
Model Reference	Properties		Components
	Name:	**Polyester coated with PVC welded**	**SolidBody 1(Boss-Extrude1)(Fatigue BiAxial Sample)**
	Model type:	**Linear Elastic Isotropic**	
	Default failure criterion:	**Unknown**	
	Yield strength:	**4.7e+06 N/m^2**	
	Tensile strength:	**4.8e+06 N/m^2**	
	Elastic modulus:	**4.57e+07 N/m^2**	
	Poisson's ratio:	**0.4**	
	Mass density:	**1,216.22 kg/m^3**	
	Shear modulus:	**5e+06 N/m^2**	
Curve Data:N/A			

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** **1 face(s)** **Type:** **Fixed Geometry**

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	**2.5**	**-5.96046e-08**	**6.28643e-09**	**2.5**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details
Force-1		**Entities:** **3 face(s)** **Type:** **Apply normal force** **Value:** **-4.3 N**

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	2.72048 mm
Minimum element size	2.72048 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	17796
Total Elements	8720
Maximum Aspect Ratio	18.494
% of elements with Aspect Ratio < 3	0
Percentage of elements with Aspect Ratio > 10	1.15
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:03

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	2.5	-5.96046e-08	6.28643e-09	2.5

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

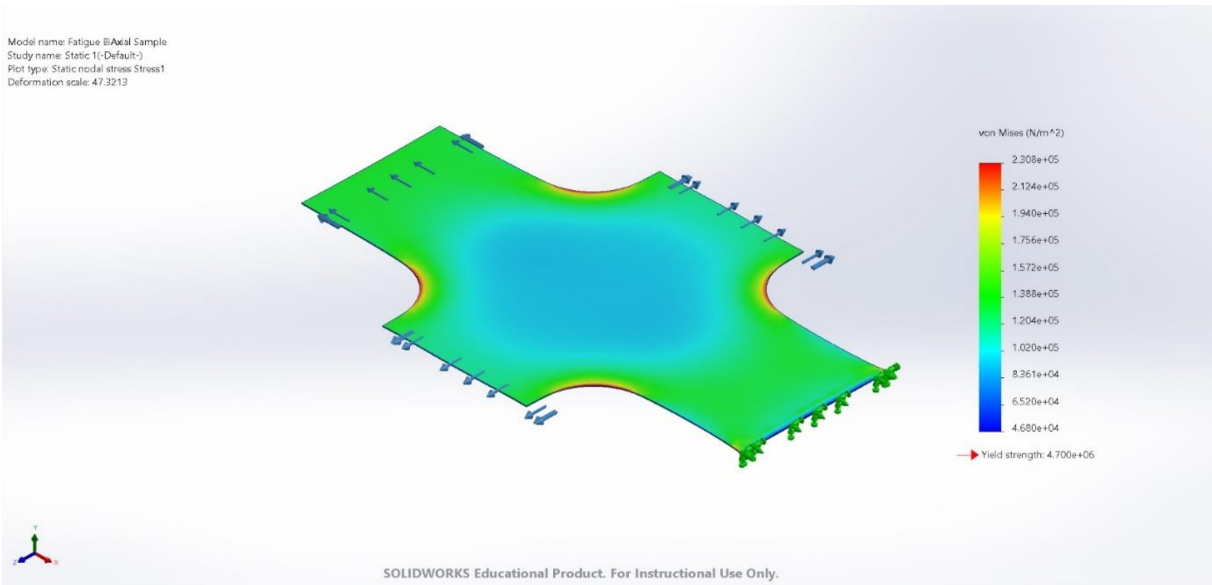
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-6.10462e-08	-5.96038e-08	4.03461e-08	9.43772e-08

Free body moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

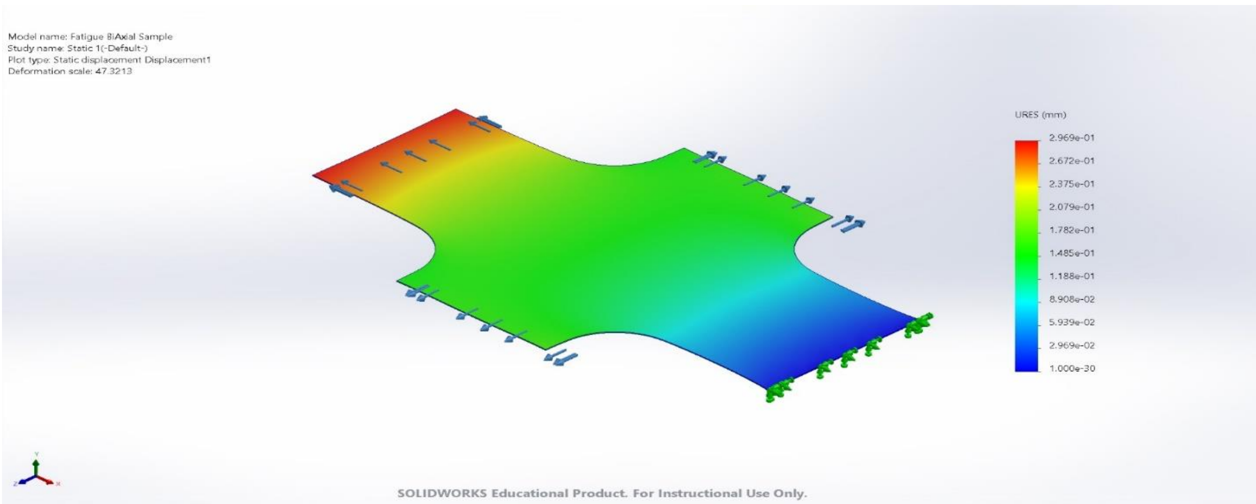
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	4.680e+04N/m^2 Node: 275	2.308e+05N/m^2 Node: 171



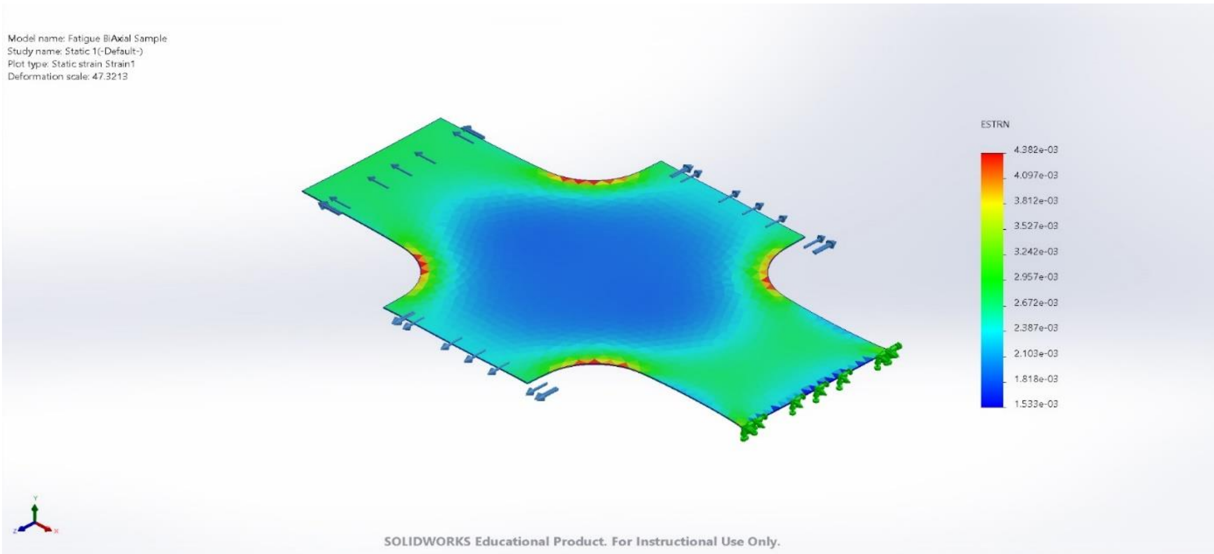
Fatigue BiAxial Sample-Static 1-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 25	2.969e-01mm Node: 12



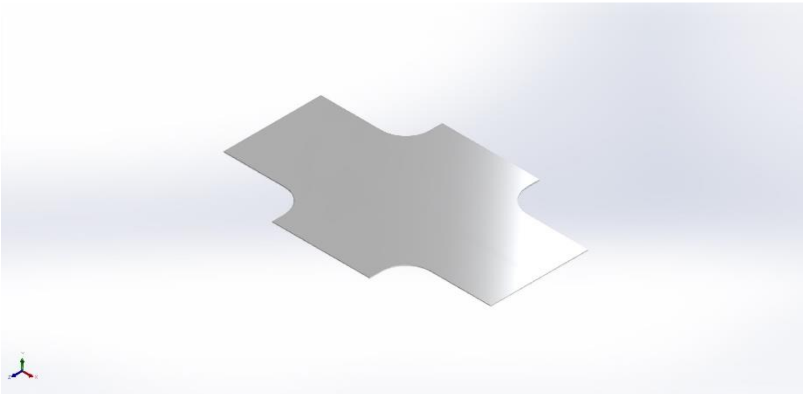
Fatigue BiAxial Sample-Static 1-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.533e-03 Element: 2867	4.382e-03 Element: 4538



Fatigue BiAxial Sample-Static 1-Strain-Strain1

Appendix E



Fatigue Simulation for Weld

Simulation of Fatigue Biaxial Sample for Weld

Date: Friday, April 14, 2023

Designer: Solidworks

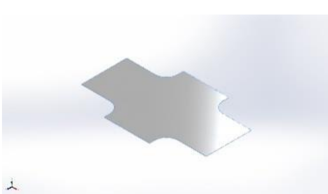
Study name: Fatigue 1

Analysis type: Fatigue(Constant Amplitude)

Model name: Fatigue BiAxial Sample fro Weld

Current Configuration: Default

Solid Bodies

Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Boss-Extrude1 	Solid Body	Mass:0.00412682 kg Volume:3.39316e-06 m^3 Density:1,216.22 kg/m^3 Weight:0.0404429 N	Apr 14 10:55:03 2023

Study Properties

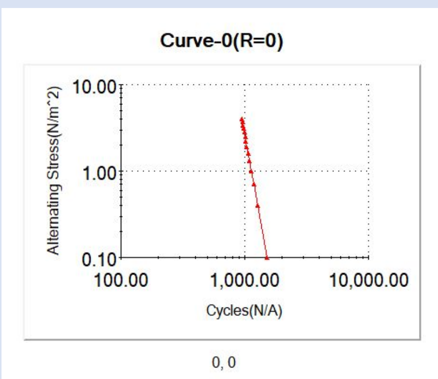
Study name	Fatigue 1
Analysis type	Fatigue(Constant Amplitude)
Event Interaction	Random
Computing alternating stress using	Stress intensity (P1-P3)
Shell face	Top Face
Mean stress correction	None
Fatigue strength reduction factor	1
Infinite life	Off

Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

Model Reference	Properties	Components
	Name: **Polyester coated with PVC welded** Model type: **Linear Elastic Isotropic** Default failure criterion: **Unknown**	**SolidBody 1(Boss-Extrude1)(Fatigue Biaxial Sample for Weld)**
Curve Data:		



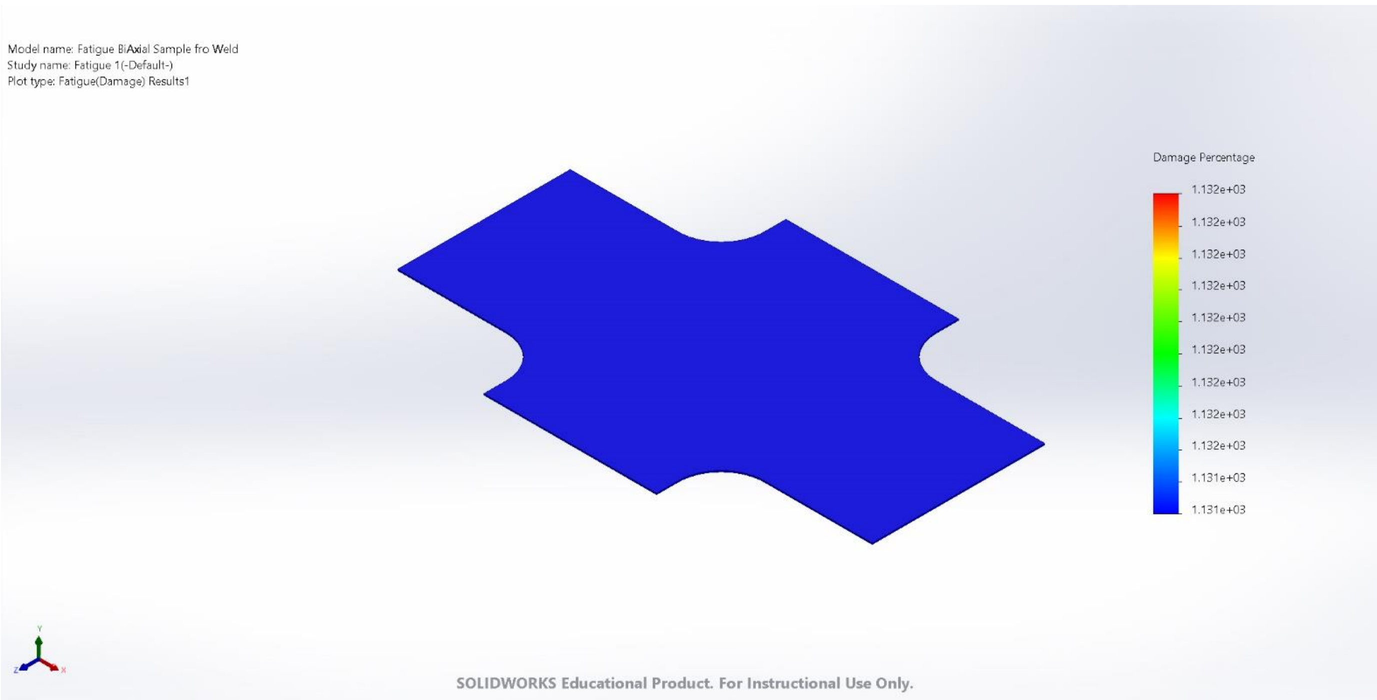
Curve-0(R=0)

Loading Options

Event Name	No. of cycles	Loading Type	Study Association		
			Study name	**Scale Factor**	**Step**
Event-1	**10770**	Zero Based (LR=0)	**Static 1**	**1**	**0**

Study Results

Name	Type	Min	Max
Results1	Damage plot	1.131e+03 Node: 1	1.131e+03 Node: 1



Fatigue BiAxial Sample fro Weld-Fatigue 1-Results-Results1

Name	Type	Min	Max
Results2	Life plot	9.520e+02cycle Node: 1	9.520e+02cycle Node: 1

Fatigue BiAxial Sample fro Weld-Fatigue 1-Results-Results2

BSL4 Suit Repair Manual

Ultrasonic Welding

Angela Asfura, Anthony Mena, & Joel Vargas
ST. MARY'S UNIVERSITY, 2023

Contents

Introduction

The purpose of this manual is to provide detailed instructions on how to repair Honeywell's level 4 safety lab suits using an ultrasonic welder. The manual aims to assist technicians and personnel responsible for repairing and maintaining these suits in ensuring their continued use and longevity.

The process of repairing the suits involves using an ultrasonic welder to fuse torn or damaged parts back together. The manual outlines step-by-step procedures to ensure the correct use of the ultrasonic welder and the appropriate techniques for repairing the suits.

The scope of this manual is limited to repairing Honeywell's level 4 safety lab suits using an ultrasonic welder. It does not cover any other types of safety suits or repair techniques.

The target audience for this manual includes technicians, maintenance personnel, and anyone responsible for repairing or maintaining Honeywell's level 4 safety lab suits. It is assumed that the audience has a basic understanding of safety suits and repair processes. However, the manual provides detailed instructions to guide even those with minimal experience through the repair process.

Process Overview

The process of repairing level 4 safety lab suits using an ultrasonic welder involves several steps. Firstly, the damaged areas of the suit are identified and marked for repair. The suit is then cleaned and prepared for repair. The ultrasonic welder is used to fuse the torn or damaged areas of the suit. Finally, the repaired suit is inspected to ensure that it meets the required safety standards and can be returned to use.

High-level Process Flowchart:

- Identify damaged areas.
- Clean and prepare the suit for repair.
- Use the ultrasonic welder to repair damaged areas.
- Inspect the repaired suit to ensure it meets safety standards.
- Return the repaired suit to use.

Key Inputs:

Inputs:

- Damaged Honeywell level 4 safety lab suit
- Ultrasonic welder – Branson LPX

Outputs:

- Repaired Honeywell level 4 safety lab suit
- Inspected and approved suit for use

Process Goals and Objectives:

The primary goal of the process is to repair Honeywell's level 4 safety lab suits using an ultrasonic welder to ensure that they meet the required safety standards and can be returned to use.

The process objectives are to:

- Identify all damaged areas of the suit that require repair.
- Clean and prepare the suit for repair to ensure that the repaired areas are free of contaminants.
- Use the ultrasonic welder to fuse the torn or damaged areas of the suit back together.
- Inspect the repaired suit to ensure that it meets the required safety standards.

Process Steps

1. Ensure that the Branson LPX ultrasonic welder is properly plugged in.
    a. The welder must be on a sturdy, level table capable of supporting at least 100 pounds.
    b. Allow enough space behind the welder to ensure that the cables connected in the back are not pinched or pressed against anything that may be behind it.
    c. If there are any problems setting up the ultrasonic welder, refer to Branson LPX Power Supply Instruction Manual section 5.3.1 (Setup Procedure)

2. Prepare the surface of the table and the suit.
    a. The surface that is being used to weld on must be free of any oils, dirt or contaminations that could potentially affect the integrity of the weld.
    b. The surface of the suit should be cleaned with isopropyl alcohol.
    c. The alcohol should not be less than 70% concentrated.

3. Using the patches provided in Honeywell's patch kit, cut out a rectangular patch that will cover the breach on the suit on all sides by at least ¼ of an inch.
    a. It is an integral part of the process as the overlapping material will help to provide an airtight weld.
    b. If the size of the breach exceeds 2 inches the suit should be considered non-repairable and should be decommissioned.

c. The patch should be free of any frayed edges or loose strands of fibers.

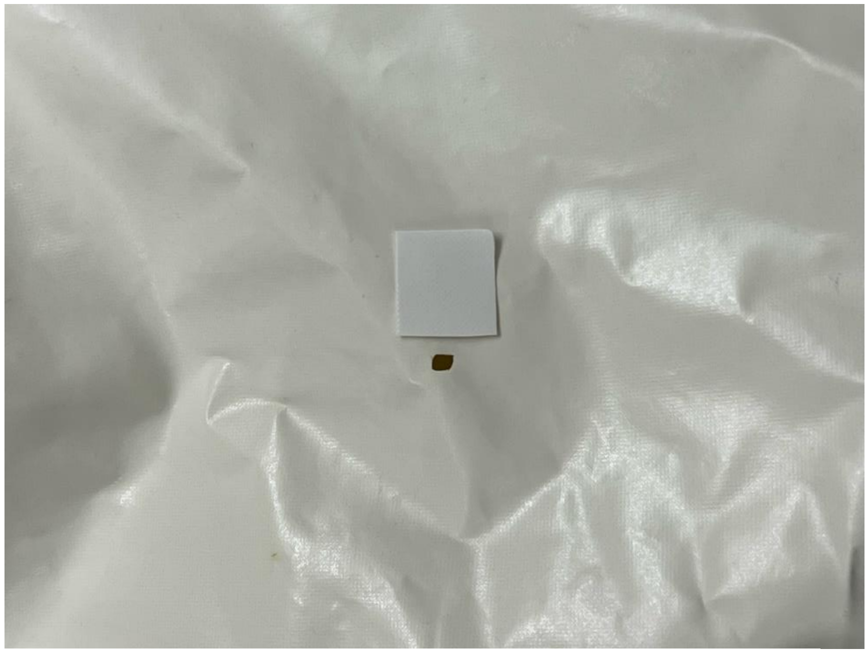


Figure 1: Tear and Patch

4. Inspect the horn and the handle for any damage that may affect the performance of the welder. (Note: The horn will not be changed unless it is damaged or malfunctioning. It is important to ensure that it has not become loose during storage in between uses.)
    a. When changing the horn clean the mating surfaces between the horn and converter.
    b. Remove any debris from the threads and the threaded hole.
    c. Using a spanner wrench tighten the horn to the converter.
    d. It should be tightened to 220 inch-pounds (24.85 Nm).
    e. Any more questions regarding the attachment of the horn to the convert should be refereed to Branson LPX Power Supply Instruction Manual section 5.3.2

5. Turn the ultrasonic welder on by flipping the power to the on position.
    a. The switch is located on the rear upper left of the power supply.

b. When the power has successfully been turned on, the LCD display will illuminate, and the fan will begin to run.

6. Select the parameter outlined in the "Welding Parameters" section of this manual.
    a. Once the proper parameters have been set, the LCD screen will display "rd4" indicating that the system is ready to weld.

7. Prepare the suit for the weld.
    a. Ensure that the suit is stable on the welding surface and will not move.
    b. The area of the suit that is being repaired must lie flat to be welded properly.

8. Clean the surface of the anvil with isopropyl alcohol and insert it in the suit behind the weld.
    a. The anvil must lay flat inside the suit parallel to the welding surface.
    b. If there are any visible areas of damage to the anvil it should be resurfaced or replaced with one that is free of damage.

9. When ready begin the welding process for the selected parameter outlined in the "Welding Processes" section of this manual.

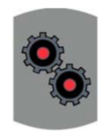
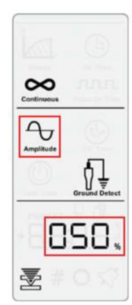
10. To ensure that the completed weld is air-tight, inflate the suit to normal operating pressure and apply a 20% mixture of soap and water to the area that has been repaired. Let the soap sit for at least 30 seconds.
    a. If the weld was successful, no bubbles should appear around the area of the weld.
    b. In the case that the weld is not air-tight, bubbles will start to form around the repair. If this is the case, please see the "Fixing Improper Welds" section of this manual.

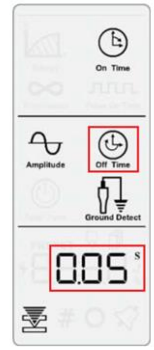
11. After allowing the soap to sit for 30 seconds without any visible signs of bubbles please see Honeywell's "Gas Tight Test" in the appendix of this manual.
    a. This test should be conducted prior to reinstating the suit for operation to ensure that the weld adheres to Honeywell's standards.

12. Once the suit has passed the Gas Tight Test, the suit is ready for use.

Welding Parameters

Continuous Welding

Step	Action	Reference
1.	Turn the power on and wait for the LCD screen to show ready.	
2.	Press the Mode/Configuration key to access the mode selection process.	
3.	Use the arrows to select the continuous mode then press the enter key to confirm the selection. After selecting the mode, it should now allow you to customize the parameters of the weld.	
4.	The amplitude icon will flash signaling that this is the current parameter being changed. Press the enter key to change this setting. Using the arrow set the amplitude to 100% and press enter to confirm. This will change the LCD screen to the next parameter.	

5.	The “Off Time” icon should be illuminated and blinking. Using the arrows change this parameter to zero and press enter.	
6.	The ready screen should appear promptly after the last parameter was confirmed. The screen will show “rd4” when these steps have been properly completed.	

Welding Processes

1. The preparation for the weld can be found in the section "Process Steps."

2. Once the preparation has been completed bring the ultrasonic welder to the welding surface.
    a. Ensure that the patch is properly aligned, and the horn is orthogonal to the material and the anvil.
    b. The area being welded should be tight and the suit should be properly secured.

Figure 2: Welding a Patch

3. Place the edge of the welder overlapping the edge of the patch by 50%.

4. Initiate the weld by pressing on the green button located on the handle.

5. Press and hold the weld for 1 minute at 6-7% power.
    c. The power will change as pressure is applied to maintain constant amplitude. The harder the horn is pressed the more the power will increase.
    d. To obtain a power output of 6-7%, the weight of the welder and slight pressure should be able to accomplish this.

6. Once the first weld is finished, repeat this process over the rest of the patch overlapping the previous weld by 50%.

7. The final weld should look like the picture outlined in Figure 3.
    a. There may be slight discoloration on the face of the patch as shown in the picture. This discoloration is normal. If the pressure of the weld exceeds the limit, burning and holes may form on the surface. If this occurs, please see the "Fixing Improper Welds" section of this manual.
    b. If the weld appears to have been properly performed and after inspection the edges are not fully welded, please refer to the "fixing Improper Welds" section of the manual.

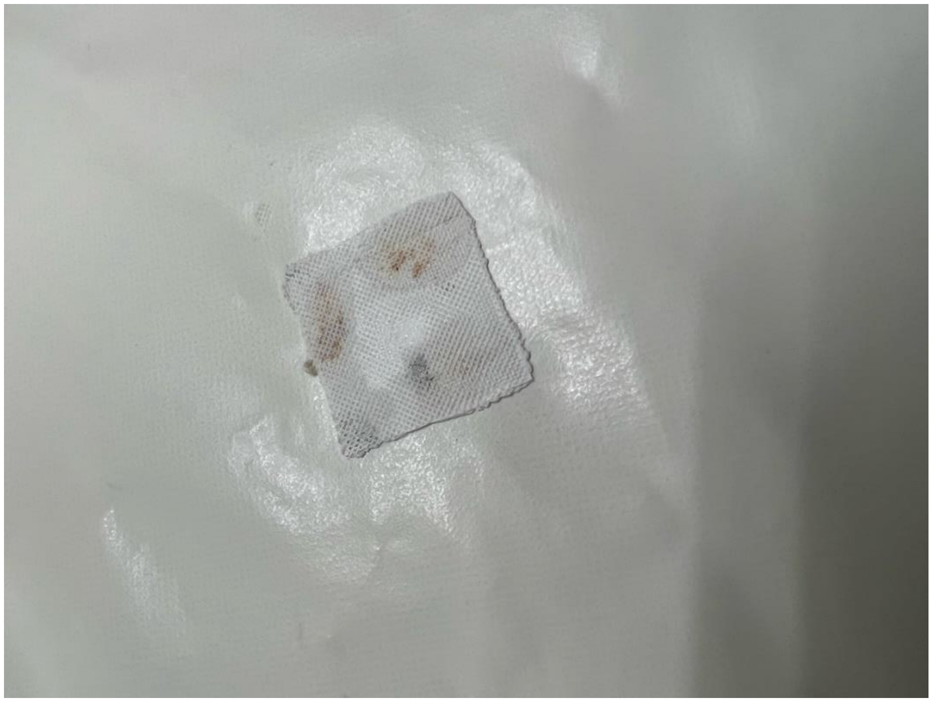


Figure 3: Final Weld

Fixing Improper Welds

This section will cover several different types of errors that can occur and how to identify them. The most common issue with welds is when they did not evenly weld the entire surface of the patch. This may cause the edges to lift up as seen in Figure 4. It is important to inspect the weld thoroughly. In some cases, it may not be as noticeable as seen on the right. This fix is simple and easy.

Figure 4: Improper Weld 1 – Unwelded Edges

Un-Welded Edges

1. First, identify the area that is not properly welded.
2. Place the horn of the welder on the edge that needs repair so that the edge of the horn is even with the edge of the patch.
3. Weld at the specified parameter using 30 second intervals until the patch has properly been welded to the suit.
4. Ensure that the weld is airtight by applying the soapy solution to the area while inflated.
5. Continue following the procedures outlined in the "Process" section.

The second error that can occur is caused by exceeding the power output of the parameter by applying too much pressure. This will cause the material to burn and can create holes or tears. Additionally, the increased pressure and heat will cause the polyester woven inside the PVC to burn and emerge from the patch. If this occurs, it will greatly increase the probability that the weld will not be airtight. An example of what this may look like is outlined in Figure 5. These types of welds will be referred to as over pressurized welds.

Figure 5: Improper Weld 2 - Over pressurized Weld

Over Pressurized Welds

1. Place a cutting board behind the patch on the inside of the suit.
2. Cut out the current patch as close to the edge of the patch.
    a. This will help to keep the repair as small as possible.
    b. Be careful to not cut the fabric of the suit if the patch size increased over two inches the suit should be deemed non-repairable and should be discarded according to Texas Biomedical Research Institute's SOP.
3. Cut a new patch out that will completely cover the hole and at least 1/4 of an inch over the sides of the hole.
4. Clean the area that is being repaired with 70% isopropyl alcohol.
5. Place the anvil inside the suit directly being the area being repaired.
6. Continue welding the patch using the normal procedure outlined in the "Process" section of the manual.

Troubleshooting, Problem Resolution, and Maintenance

Damaged Anvil

1. Identify the damaged surface of the anvil.
2. Tape a clean sheet of #400 emery cloth (or finer depending on the severity of the damage) to a clean, smooth, flat surface.
    a. A piece of plate glass would be an effective surface.
3. Hold the anvil flat on the emery cloth. Obtain a firm grip and start to move the anvil back and forth until the damage is no longer visible.
4. Once the damage is no longer visible, repeat steps 1-3 using a sheet of #600.
    a. This will ensure a flat smooth finish.
5. After using the #800 emery cloth the anvil will be ready to use.

Trouble shooting

1. Loud, high-pitched noise.
    a. This could be an indication that the horn has acquired a crack.
2. Power supply overload
    a. Refer to Branson LPX Manual

Safety and Environmental Considerations

The process of repairing Honeywell's level 4 safety lab suits using an ultrasonic welder involves some potential hazards that need to be taken seriously to ensure the safety of personnel and the environment. Some of the hazards associated with this process include:

- Electrical shock: The ultrasonic welder uses electricity, which can be hazardous if not handled properly.
- Ultrasonic noise: The ultrasonic welder produces high-frequency noise, which can be harmful to the ears if proper hearing protection is not used.
- Fire hazard: The welding process generates heat, which can be a fire hazard if not handled properly.
- Chemical exposure: The isopropyl alcohol used to clean the suit and welding surface can be harmful if inhaled, ingested, or comes into contact with the skin.

To mitigate the potential hazards associated with this process, the following precautions and protective measures should be taken:

- Personnel should wear appropriate personal protective equipment (PPE), such as earplugs, safety glasses, gloves, and an apron.
- Ensure that the ultrasonic welder is grounded and properly installed before use.
- Do not touch the horn or anvil while the ultrasonic welder is in use.
- Only use the isopropyl alcohol in well-ventilated areas and wear appropriate PPE when using it.
- Avoid smoking or using open flames near the welding area.
- Do not attempt to repair the ultrasonic welder if it is malfunctioning. Contact a qualified technician for assistance.
- Proper handling and disposal of materials include:
- Store the patch kit, ultrasonic welder, and PPE in designated areas when not in use.

- Dispose of any used patches and contaminated materials in designated hazardous waste containers.
- In case of an accident or spill, follow the emergency procedures below:
- In case of an electrical shock, immediately turn off the power and call for emergency medical services.
- In case of a fire, turn off the power and use a fire extinguisher to extinguish the flames.
- In case of chemical exposure, immediately remove contaminated clothing and rinse the affected area with water for at least 15 minutes. Seek medical attention immediately.
- In case of any other accidents or spills, notify the supervisor immediately and follow the established emergency procedures.