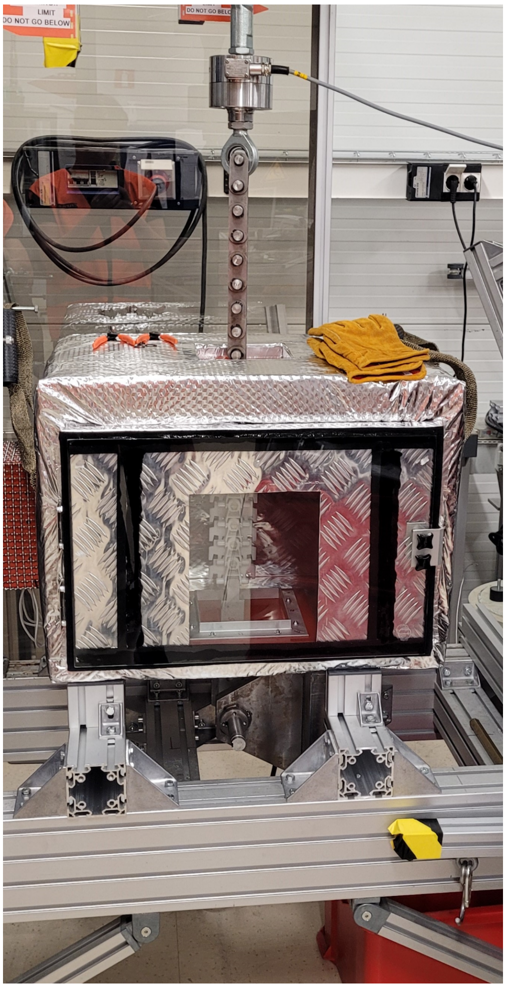

Construction of a temperature-controlled chamber

Degree project for mechatronics engineering

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DEGREE PROJECT 2023

Developing temperature-controlled chamber to test mechanical properties of conveyor components

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Abstract

This degree project aims to construct a temperature-controlled chamber for evaluating the strength and elongation of conveyor system components at temperatures spanning from room temperature to 100 °C. The objective is to improve the quality of the company's products by testing their conveyors' mechanical properties, including tensile strength, yield strength, and ductility, at various temperatures. This report describes the construction of a temperature-controlled chamber with a temperature range of ambient to 100 °C, including its heating element, temperature sensor, control system, insulation, air circulation ventilation, and safety features.

Also discussed are the materials used to construct the chamber, such as ceramic insulation and aluminum box. In its conclusion, the report highlights the project's limitations, namely the insufficient budget for the chamber's construction, potentially leading to inaccurate temperature regulation, and the fact that the chamber will be partially open, resulting in temperature fluctuations.

Acknowledgments

We would like to convey our appreciation to FlexLink for giving us the chance to work on this degree project, and in particular to the company's test department. They have been extremely helpful and supportive throughout the entire project. Additionally, we want to thank our supervisor for his wise advice, constructive criticism, and comments. We also want to thank our coworkers, who helped us out during the project in various ways and gave us advice. Finally, we want to thank the university community and the literature in our field for their contributions, which gave us the tools and resources we needed to perform the research.

Contents

1
Introduction

This chapter provides both background information on the company and on the project. It also introduces the thesis work and covers the project's objectives, goals, and limitations.

1.1 Background

FlexLink revolutionized industrial production forty years ago by developing innovative modular conveyors that enable manufacturers to design flexible manufacturing lines. Since the 1980s, the conveyor manufacturing concept has been developed, expanded, and commercialized all over the world. Today, FlexLink is the industry leader in flow solutions for production lines and chain conveyors.

FlexLink has a wide range of clients, from regional producers to multinational enterprises and from end-users to machine makers. The business is a top supplier of premium solutions to manufacturing sectors like those for food, drink, tissues, personal care, pharmaceuticals, cars, batteries, and electronics.

The company has a test department, which is responsible for testing and ensuring the quality and functionality of the company's products and systems before they are released to their clients. This includes conducting experiments, analyzing results, and verifying the performance of the products under various conditions to ensure they meet the specified requirements and standards. To do this, FlexLink in part uses their tensile test machine, but they want to better understand how the strength and elongation of a component change when doing the tensile tests at different temperatures.

1.2 Aim and requirements

The objective of this project is to construct a chamber capable of maintaining a steady temperature within an adjustable range of room temperature to 100 °C. The chamber must include a fan to ensure uniform heat distribution, two holes (one on the upper and one on the lower side) for inserting test components, and a mechanism for minimizing heat loss and maintaining temperature stability. The chamber should be constructed of durable and heat-resistant materials and feature a windowed door to allow visibility inside.

Furthermore, this chamber must integrate with an existing tensile test machine, necessitating a compact, portable, and easily transportable design to facilitate use and storage. The chamber should also be versatile enough to function as a standalone system with the option of incorporating an elongation measurement

1.3 Goal

Goal The goal of the project is to increase the quality of the company's products by doing tensile tests at different temperatures. The company will hopefully be able to test the mechanical properties, such as tensile strength, yield strength, and ductility, of their conveyors at different temperatures. This information can be used later to change the material properties of the conveyors to fulfill the customer's demands.

1.4 Limitations

This project will be at a company that has a limited budget to allocate to building the chamber, which can limit the selection of available components. This might affect the accuracy or the rate at which the temperature of the chamber can change. Moreover, the chamber will be partly open, which is going to cause the temperature to fluctuate a bit.

As of now, in the chamber, only the temperature is going to be regulated, not, for example, the humidity. The chamber will also make use of existing elongation and tensile testing equipment.

2
Theory

This chapter describes the construction of a temperature-controlled chamber with a range between ambient temperature and 100 °C. It also describes various methods for constructing the portable heating chamber, as well as the isolation materials and electronic components.

2.1 Chamber

The desirable chamber should be capable of regulating the temperature between room temperature and 100 °C; it aims to create a controlled environment in which the temperature can be precisely regulated and maintained. This chamber will be used for material testing and must have specific dimensions and properties to be compatible with an existing tensile testing machine.

This report will later describe in detail the chamber's main components, including its heating element, temperature sensor, control system, insulation, fan for air circulation, and safety features.

2.1.1 Methods for constructing a portable heating chamber

A portable heating chamber can be constructed using various methods. The first approach involved purchasing a portable oven and modifying it to suit the project's requirements. Unfortunately, finding a suitable oven size with two openings proved challenging, and locating the placement of the heating element and other electrical components proved difficult.

The second method involved procuring aluminum sheets and cutting them into straight pieces with clean edges. However, this approach necessitated bending and welding tools that were not readily available. If a profile structure was employed, pop rivets and a pop rivet gun were used to join the pieces, resulting in a heavy and unwieldy chamber.

The third method entailed purchasing an appropriately sized metal box and modifying it to function as an oven. This method appeared to be the most practical, cost-effective, and efficient means of constructing the heating chamber. A box of appropriate size was selected for the project and modified accordingly. In view of its lightweight, heat-resistant, and rust-resistant properties, aluminum was chosen for this purpose.

2.2 Isolation

The materials used to construct the chamber can also affect temperature regulation and system stability. The current project utilizes ceramic insulation to isolate the chamber.

Ceramic insulation is a form of high-temperature insulation material that is frequently used in applications in industry where high temperatures must be maintained or regulated.

The process of creating ceramic fibers involves fusing ceramic materials, spinning them into fine fibers, and then weaving or compressing the fibers to create insulation products [2].

The key features of the ceramic glass used in this project include:

- High temperature resistance up to 1400 °C
- Low thermal conductivity, making it an effective insulator for the chamber.
- Lightweight and flexible, which served this project because the chamber must be portable.

2.3 Electric components

The temperature chamber has been constructed with the components specified:

- A fan is used to circulate the air within the chamber, ensuring that the temperature is uniform.
- Buzzer (alarm): The buzzer acts as a loud alert when the temperature inside the chamber exceeds the acceptable range.
- An SSR, or solid state relay, is an electronic switching device used to control the heating element through the AC contactor. It activates and deactivates the heating element based on the thermocouple's temperature readings, thus maintaining the desired chamber temperature.
- Lamp Indicator: A lamp indicator is used to display the temperature controller's status. It displays whether the heating element is operating normally or whether there is a problem.
- Thermocouple of the K-Type: A thermocouple is a form of temperature-measuring electrical device. The K-type thermocouple is used in this project because it can accurately measure a broad range of temperatures.
- Heating element: It is used to heat the chamber to the desired temperature. It is controlled by the SSR and switches on and off based on the thermocouple's temperature readings.
- Circuit Breaker Switch: The circuit breaker switch is a safety device used to protect the chamber's components from electrical fault-related damage.
- AC Contactor: An AC contactor is an electronic switching device used to control the heating element, fan, and alarm in accordance with the PID's signals. It is regulated by the SSR and guarantees the heating element is turned off when the chamber temperature exceeds the intended range.

- PID Temperature Controller: The PID controller is used to regulate the chamber's temperature. It receives input from the thermocouple and adjusts the heating element output using an algorithm for regulation to maintain the desired temperature.
- Switches: The temperature chamber is equipped with two switches to control the heating element and alarm. These switches serve the purpose of powering on and off the respective components as required.

2.3.1 PID-Controller

The PID controller utilized in this project has a temperature range of -199 °C to 1300 °C. PID is a control algorithm utilized in a variety of industrial control applications to maintain a setpoint or objective, in this instance, temperature. It functions by continuously monitoring the actual process variable, comparing it to the setpoint, and computing an error signal used to modify the control output [1].

The PID controller uses proportional, integral, and derivative tuning parameters to determine the control output. The proportional term computes the control output based on the current error signal, while the integral term accounts for the error's accumulation over time, and the derivative term determines the error signal's rate of change [1].

To prevent damage to the chamber's components, the PID controller has been programmed to activate an alarm and cut off the heating element when the error signal exceeds a threshold that has been set.

2.3.2 Circuit diagram

The PID controller is connected to a solid-state relay, also known as an SSR. At pin 11, a switch is used to turn the heating element on and off. The SSR is connected to the AC contactor and turns on the heating element when a signal is received from the PID controller through the SSR to the AC contactor.

The fan operates when the switch (SW2) is closed, and there is no alarm. When an alarm signal is received from the PID controller to the AC contactor, electricity flows through the AC contactor coil, which turns off the heating element and the fan. However, it also makes the buzzer sound and creates a holding circuit that keeps the buzzer working even if the alarm signal from the PID controller stops. The holding circuit is a safety procedure that keeps the buzzer on and turns off the heating element until the operator checks for any faults and resets the alarm by turning off the switch (SW2).

Three lamp indicators have been used in this project. LA2 indicates that the power is on and that electricity flows through the PID controller. LA1 displays whether the heating element is on or off, and lamp 3 is a buzzer and lamp at the same time, which indicates whether the alarm is on or off. Below, in figure 1, the circuit diagram is displayed.

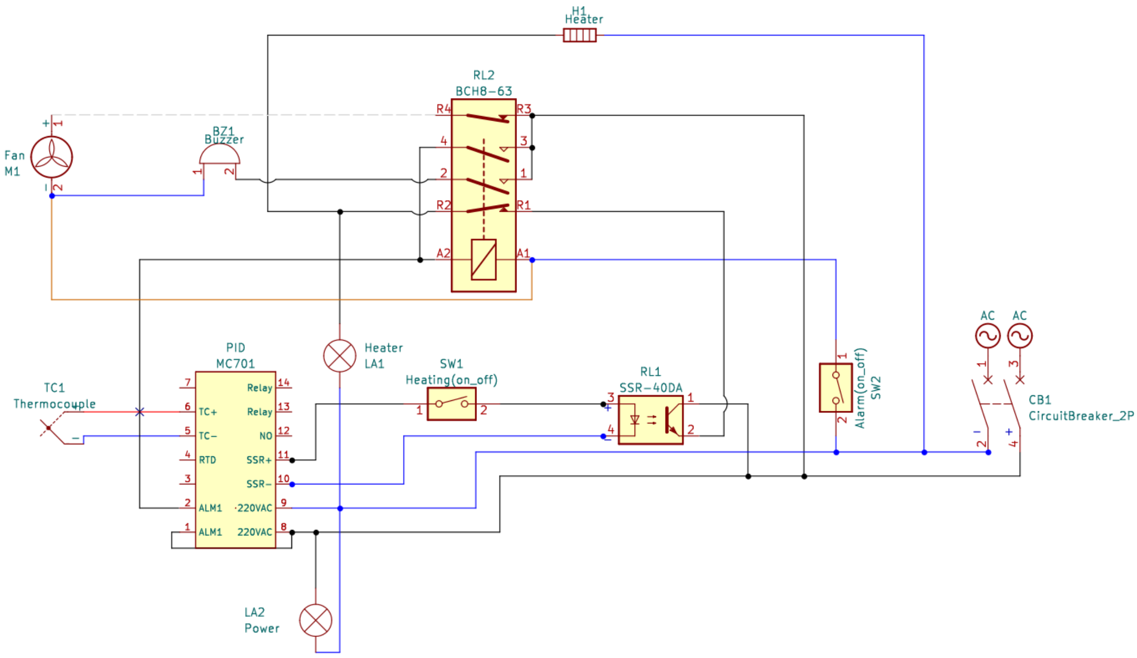

Figure 1: Circuit diagram.

2.4 Test object

The objective of this project is to perform a tensile test on a plastic conveyor, which serves the purpose of transporting materials or products from one point to another. The conveyor is composed of a series of interconnected plastic chains that form its surface. While the width of the conveyor varies depending on its intended use, the length of the test object is five links, which fall within the range of 100 mm to 250 mm. One of the types of test objects can be seen in figure 2 below, and figure 3 shows the same type on a conveyor belt.

Figure 2: Five conveyor links.

Figure 3: Conveyor belt.

The tensile test requires the application of a tensile force to a sample of the conveyor being tested. The sample is then clamped at each end using the grips of the tensile test machine, which subsequently applies a pulling force until the sample reaches its breaking point. Throughout the test, force and elongation are measured and recorded. This data is then analyzed to calculate the mechanical properties of the material, such as the ultimate tensile strength, elongation at break, and modulus of elasticity, based on different temperatures controlled by the aforementioned chamber.

3
Methodology

To construct the chamber, the initial step involved the procurement of the necessary components, followed by the assembly of the chamber, which ultimately concluded with the execution of tests and verification procedures to ascertain that the intended objectives were achieved.

3.1 Finding components

In adherence to a reasonable budget, the search for components was primarily conducted on Amazon. Because of the availability of a wide range of items at a low cost. The downside was that some components had relatively long delivery times, and maybe quality would have been better elsewhere, although everything worked as advertised

3.2 Building the chamber

The first step in building the chamber was to install the fan and the heater. This is shown in figure 4 and 5.

Figure 4: Fan and heat element.

Figure 5: Fan motor.

The step after that was to make two holes, one at the top and one at the bottom, to enable connection to the tensile test machine. The hole was covered with two rubber rugs to isolate it and was installed with four cuts each to allow the connecting chain of the tensile test machine to pass through. A two-cm-high steel list was placed along the sides of the hole, both inside and outside. This is to protect the isolation and also put the rubber in place. After that, the isolation was installed on all sides except the door and was put in place by metal straps. Figure 6 below shows how the rubber rug is installed and attached with metal lists. Figure 7 shows the isolation being fastened with metal straps.

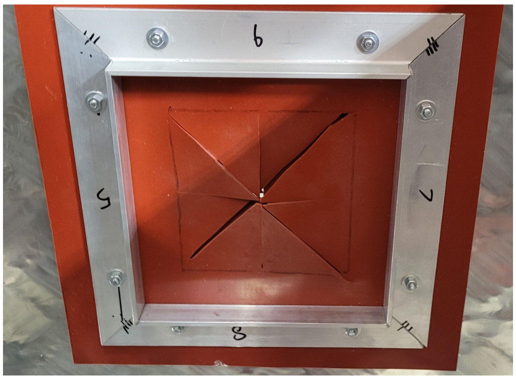

Figure 6: One of the holes, from the inside.

Figure 7: The isolation and metal straps.

Aluminum foil was used to cover the isolation for protection and to make it more aesthetically pleasing. Around the door, three stacked layers of thermal bands were needed in order to isolate it enough not to be too hot. Silicone was used for attachment, and it was covered with aluminum foil. Handles were positioned on both sides of the chamber to make it easier to carry. A protective cover was made for the fan motor and cables. Rubber was used as a conductor between the metal case and any current leakage or loose cables. Below, figure 8 shows how the aluminum foil looks on one of the sides, how one of the handles was installed and how the fan motor along with the cables are protected. Figure 9 shows how the protective cover was installed around the fan and heater.

Figure 8: The aluminum foil, protective cover, handle, and cables

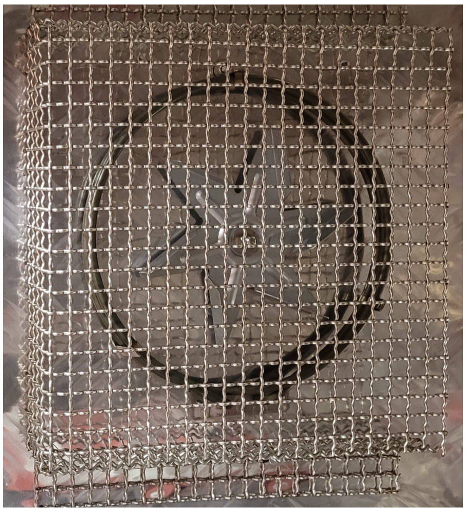

Figure 9: Protective cover inside the chamber.

To insulate the door and provide visibility, two glass panels were installed, one on the inside and the other on the outside. Both glasses were equipped with a seal to create a gap between them, allowing air to act as an insulator. The glasses were securely attached with high-temperature silicone. Figures 10 and 11 show how the glasses are attached to the door.

Figure 10: Glass on the inside of the door.

Figure 11: Glass on the outside of the door.

Originally, the door opened downward, but the hinges were moved to the side for it to open from right to left. This is to make it easier to reach in and install the component. A handle and a lock mechanism were then installed. Also, a hole was drilled in the chamber for the temperature sensor to be mounted. Below, the figure 12 shows the handle for opening the door and also the lock works.

Figure 12: Handle and the lock mechanism.

As depicted in the circuit diagram, the electrical components were installed inside an electric box. The temperature sensor was connected directly to the box. The cables for the fan and heater from the chamber to the electric box were connected together using a protective contact plug with an earth plug built-in. Holes were made in the door to fit the lamps and switches, and the display of the PID controller was mounted externally. The components mounted external can be seen in figure 13 and how the components were connected can be seen in figure 14.

Figure 13: Electric box, front side.

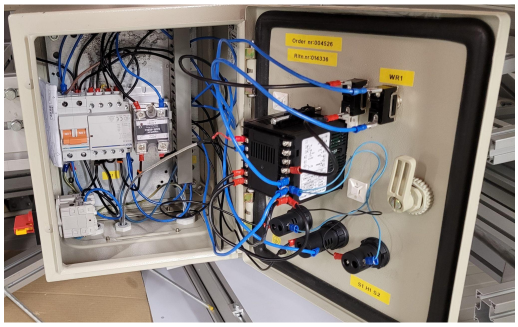

Figure 14: Inside the electric box.

Below, figure 15 shows how the chamber is used with the tensile test machine with a component inside.

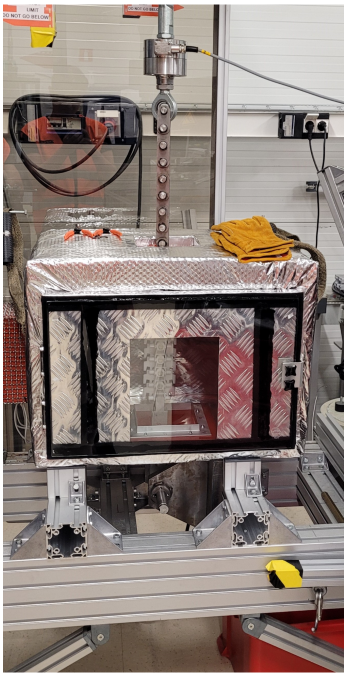

Figure 15: Chamber inside the tensile test machine.

3.3 Testing and verification

Testing is a crucial step to ensuring the functionality of the chamber, as it helps identify any potential issues or areas that require better insulation. For instance, during initial testing, it was observed that the area around the door was getting hot, and the thermal band, attached with aluminum tape, was not sufficient to prevent heat from escaping, and the tape got loosened. Therefore, to improve the insulation, three stacked layers of thermal bands were used, and aluminum foil was used to cover it instead, as it was found to attach better in high temperatures. Moreover, in order to improve the chamber's overall safety and performance, several changes were made, including the calibration of the door and adjustments to the circuit diagram. Additionally, other enhancements were implemented to optimize the chamber's functionality.

The PID controller came preinstalled with values for P, I, and D. These worked relatively well but were improved after some fine-tuning. The chosen values were P = 25, I = 170, D = 20, and t = 20. The sequence of events with a set value for the chamber at 100 °C is that the temperature will rise fast until around 70 °C, with the heater almost on the entire time. After that, the heater is on less and less, and the last 5 °C takes about a minute. Once the temperature reached its target, the heater was on about 5–7% of the time. This does not create any overshoot, and since it takes a while for the testing object to reach the temperature of the surrounding air, the extra time for the last 5 °C doesn't matter that much.

The reason not to have an overshoot is that it could have an impact on the component and also the alarm. The alarm would have to be set above the overshoot and would take longer to turn on if the chamber's temperature just continued to rise above the set value. In the test runs, after the desired temperature was reached, the real temperature would be around 1 °C below to 1 °C above the setpoint until the user wanted something else, and it would seldom differ more.

After testing with another thermometer, it was established that the temperature in the chamber did not differ by more than 1 °C or 2 °C. For the test object to reach the desired temperature, it takes around 5–10 minutes. This was tested with a thermal camera, which only measured the surface temperature and did not show the temperature inside the component.

4 Result

This chapter discusses the evaluation of the chamber's functionality and the veracity of the tensile test data while the chamber is working. It describes the results of the conducted experiments and how the chamber will assist FlexLink in optimizing the product's design and manufacturing.

4.1 Assessing chamber functionality

After testing and data analysis, it has been determined that the chamber functions as intended. The PID controller's temperature reading is consistent with the temperature reading from a portable temperature sensor. The PID controller maintains a constant state and responds appropriately to changes in the setpoint while precisely regulating the temperature within the chamber.

The alarm function of the chamber is fully functional. It is programmed to activate promptly when the temperature exceeds the threshold. The alarm function is an essential safety feature, and its dependability is essential to the chamber's overall safety.

4.2 An Evaluation of the Accuracy of Tensile Test Data Produced by the Chamber

Very good outcomes have been obtained using the chamber on the tensile test machine. The chamber effectively raised the product's temperature to the desired level, guaranteeing that the material was evaluated under the proper circumstances. A thermal camera was used to closely monitor and double-check the temperature, ensuring the testing's accuracy and dependability.

Two tests were conducted, one at room temperature, and one at 80 °C. By analyzing the results from the tensile test machine, it could be observed that the product became more ductile with the temperature increase, and there was a noticeable change in the stress-strain curve. Specifically, at the high temperature, the curve stretched out and the plastic area increased. The product was able to undergo more deformation before breaking, and the test took about 2 minutes longer with the machine accelerating the force at the same speed. The machine was not fully calibrated this time, so it did not show the exact force applied, but data could be read from the appearance of the graph and the difference in durations. In figure 16 below, the result of the tensile test machine with the test object at room temperature can be observed.

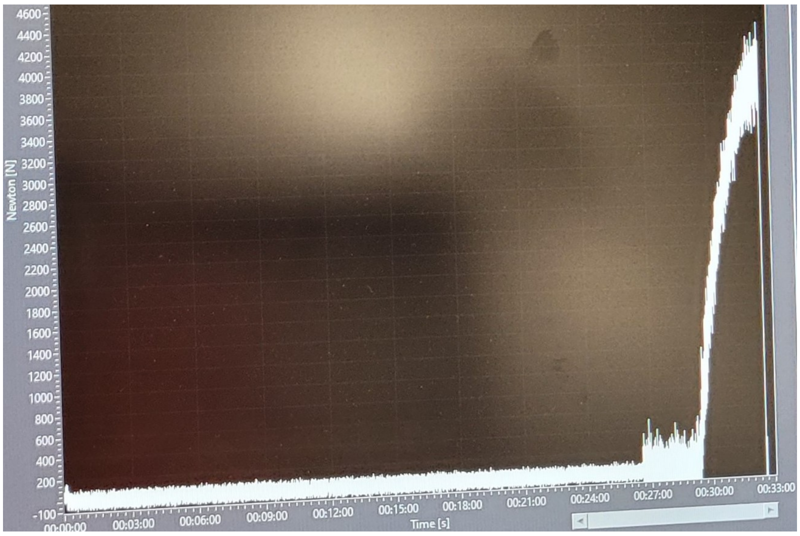

Figure 16: Tensile test result at room temperature.

The next test was at 80 °C and is shown in figure 17 below.

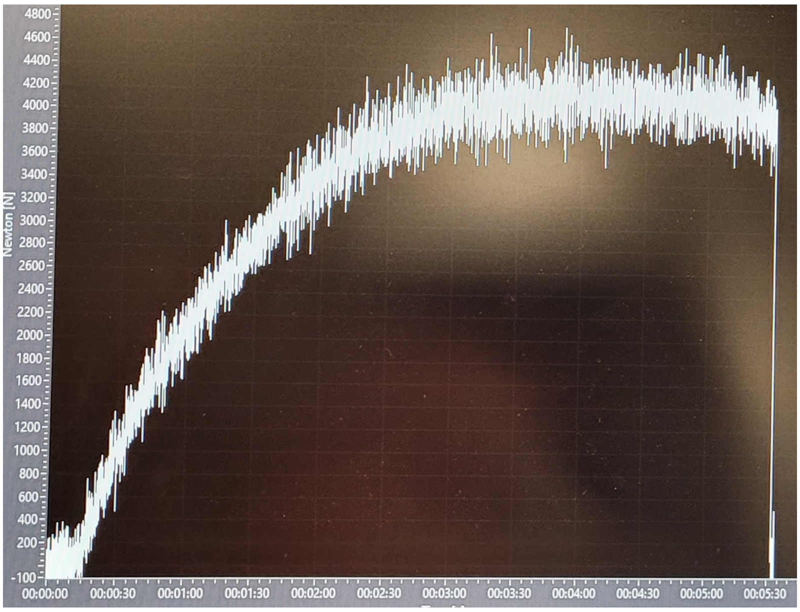

Figure 17: Tensile test result at 80 °C temperature.

Overall, using the chamber will definitely help FlexLink better understand how the product behaves at various temperatures. They will be able to further optimize the product's design and production with the use of this information.

5
Discussion

As mentioned before, the chamber worked as intended. However, compromises had to be made, and some solutions worked very well while others could have been improved.

The electrical side of the project performed without any issues and integrated well with the rest of the chamber. The heater was very effective, heating up the chamber to 100 °C in around 5 minutes. The fan also functioned well, distributing heat evenly in the chamber while keeping noise levels to a minimum.

The two rubber plates at each hole were insulated very effectively, and the attachments for the test component could easily pass through. If the chamber is used frequently, there could be some wear on the rubber, and it might need to be changed. The rubber on the inside would be easy to change, but not as easy on the outside. It would work with only one plate, although it would not insulate as much. A possible solution would be to have two plates on the inside.

The insulating material used in the chamber was very effective and barely leaked any heat. However, the metal straps that were attached leaked some heat. The two glasses used were very effective in containing the heat and did not get particularly warm, but the door was quite heavy, although the chamber was not close to falling forward when the door was fully open.

Throughout the project, decisions had to be made regarding whether to prioritize insulation or weight and cost savings. The chamber was well insulated, which made it heat up quickly, kept temperature fluctuations to a minimum, and prevented most surfaces from getting too hot outside the chamber, except for the metal list around the holes. The trade-off was that the chamber was quite heavy, but it was still manageable to carry alone. The aluminum foil worked mostly well, but it could possibly get cut in contact with rough edges, and the glue might loosen over time.

The decision to buy an aluminum box worked very well, making it cheaper and easier to build the chamber. The decision to make the door open from right to left instead of up and down was tricky, but it made it easier for the user. One tricky part was aligning the hinges so that the glass fitted well with the list around the door and also with the closing mechanism, while the hinges and lock needed to be fitted over the insulation. The lock was not perfect and needed adjustments to keep the door shut, making it a bit harder to close. A better closing mechanism would probably have been a lock that was connected to the side of the chamber and was more secure.

To keep the cost relatively low, some lower-quality components were used, and some weight was added to prioritize insulation. A few things could have been improved upon, and another lock would probably be better. Overall, the chamber works very well and can provide valuable data for Flexlink.

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