MAE 494/598: Mechatronics Engineering Design & Manufacturing
Prof. Dr. Cindy (Xiangjia) Li

Application Project Report

Title: Hot Water-Waste Harvest Device

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Introduction

The hot water waste harvest device is a thermoelectric energy conversion technology that generates electricity from waste heat sources, such as hot water pipes. The basic working principle of the device consists of a thermoelectric material(Sb_2Te_3) that is attached to the surface of the hot water pipe using a suitable bonding agent. When the hot water flows through the pipe, it heats the thermoelectric module, creating a temperature difference. This temperature difference generates a voltage difference, which drives an electrical current through the p-type and n-type legs, generating electricity.

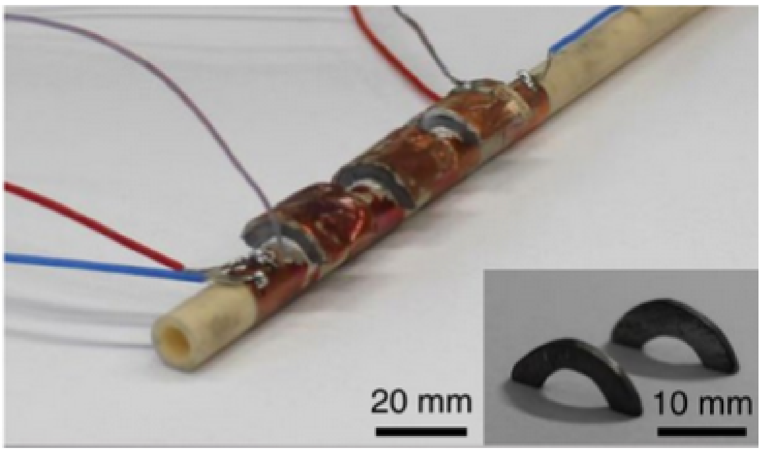

Figure 1: Sample picture of thermoelectric material [1]

Objectives

1. Design a thermoelectric material part that can be attached to hot water pipes and efficiently converts thermal energy to electrical energy.
2. Investigate how different manufacturing parameters affect the performance of the thermoelectric set up.
3. Measure the power output of the thermoelectric set up at various temperatures and use the harvested energy to run a small electrical appliance.

Construction and Features

This device using N-type and P-type material with SB2TE3 material in between the pipe consists of the following basic construction and features:

1. Tube: It is the pipe that carries the hot water waste and it is made of resin..
2. N-type and P-type materials: These materials are placed in between the inner and outer pipes and are thermoelectric materials that generate electricity when a temperature difference is applied. The N-type material has an excess of negatively charged electrons, while the P-type material has an excess of positively charged holes.

   SB2TE3 material: It is placed in between the N-type and P-type materials and acts as a thermoelectric converter, efficiently converting the temperature difference between the hot water waste source and the cold environment into electricity.
3. Insulation: The device is covered with insulation material to prevent heat loss and maintain the temperature gradient between the hot water waste and the cold environment.
4. Power generation and storage: The generated electrical power can be used to power various devices or can be stored in batteries for later use.

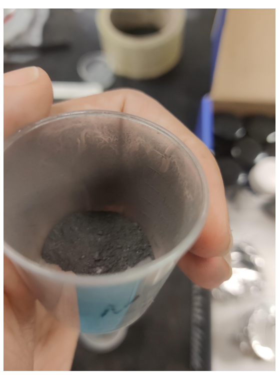

Figure 2: P-type material

Figure 3: N-type material

Figure 4: Resin used

The process used to produce the mold is shown in Figure 5:

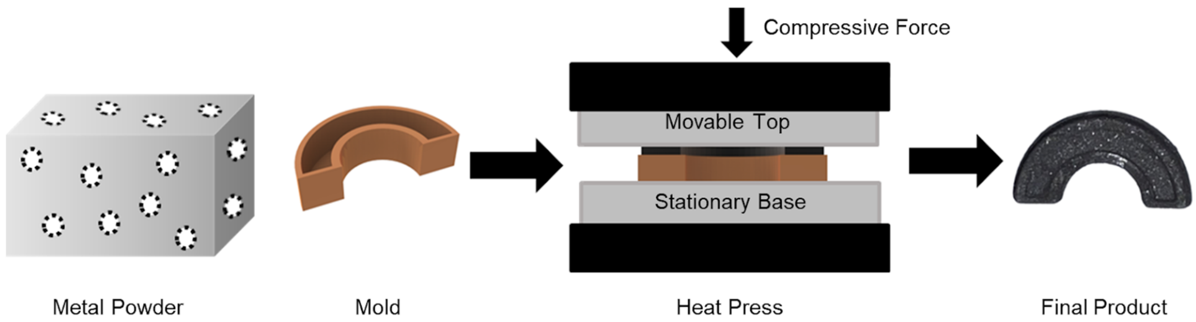

Figure 5: Material pressing procedure [1]

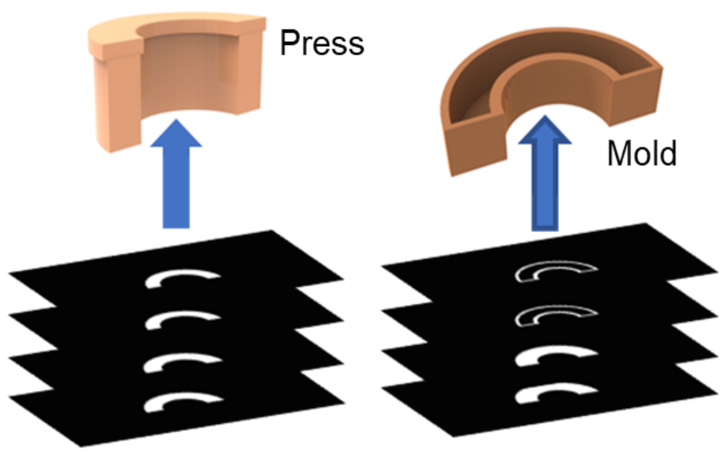

Figure 6: Slices of the mold and press (for 3D printing) [1]

Pressing is commonly used to shape the N-type and P-type with SB2TE3 material. During the pressing process, the powder mixture is placed in a mold and compacted into a desired shape using varying force. The pressed material is then sintered to create a solid and highly conductive material.

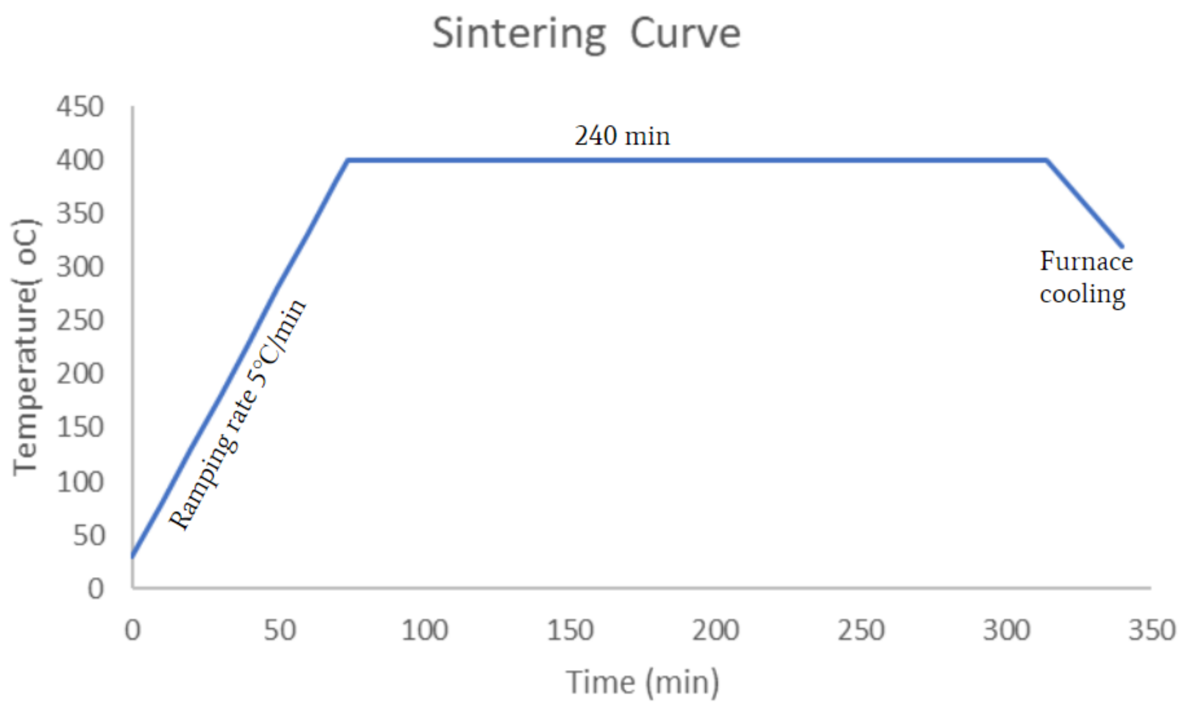

Figure 7: Sintering Curve for the parts (ramping rate of 5°C/min, followed by dwell of 4 hrs at 400°C, and finally, furnace cooling to room temperature.

The sintering process is a crucial step in the construction of the hot water-waste harvest device using N-type and P-type materials. It is the process of heating the powders at high temperatures to create a solid material.

During the sintering process, the ground N-type and P-type materials are compacted into the mold shape. The compacted material is then heated at high temperatures, typically around 350 to 450 degrees Celsius, for several hours in a controlled atmosphere.

The process causes the particles in the powder to bond together, creating a solid material that is highly conductive and has good thermoelectric properties. This also helps to improve the efficiency and performance of the device by reducing thermal losses and increasing the electrical conductivity of the materials.

After the sintering process, the solid N-type and P-type with SB2TE3 material are placed in between the tube of the device, and the device is assembled, insulated, and tested. The process makes the device to efficiently convert the temperature difference between the hot water waste and the cold environment into electricity.

Mechatronics Systems

The system consisted of 3 main components:

1. The Thermoelectric Material
2. The hot water tube
3. The electrical components/circuitry used to test whether the TE part was producing any electricity.

In addition, we used the following pieces of equipment during the manufacturing of the TEG materials:

1. SLA 3D Printer
2. Hot Press
3. Arduino Pressure Sensor
4. Furnace
5. Ultrasonic Cleaner

Details of System Components

Thermoelectric Material

The material used was Bismuth Telluride, and it was doped with Antimony. This produced two material variants, i.e, the n-type and p-type materials. We grinded the material down so it was finer than 100 **µ**m. It was then packed into molds and heat pressed. Finally, it was sintered in the Furnace. The thickness of the part was 1 mm and the inner and outer diameters were 7.4 mm and 10.4 mm, respectively.

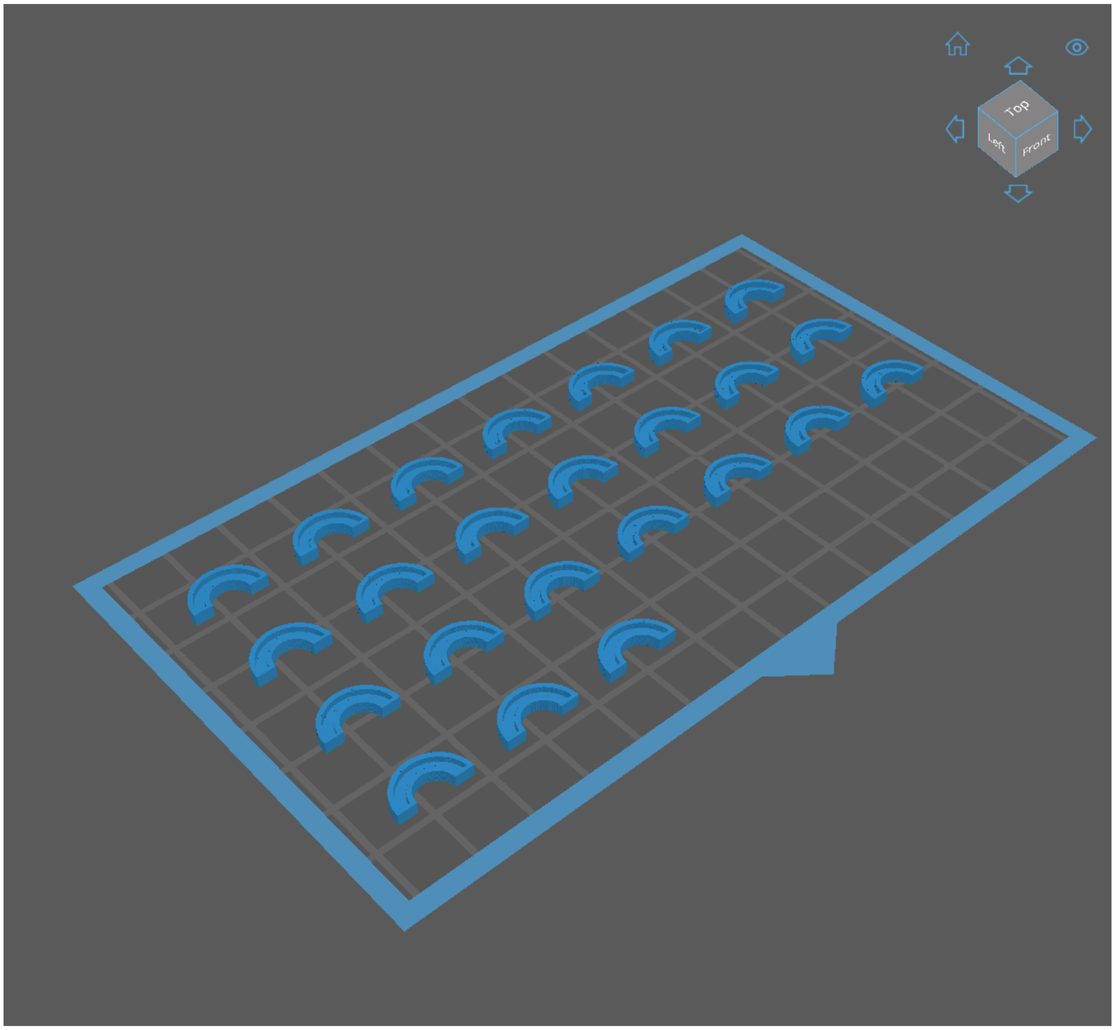

Figure 8: Molds after being sliced in Chitubox

Figure 9: Mold for the TE part

Figure 10: TE part after sintering

Hot Water Tube

The hot water tube was designed to act as a test bed for the TE junction. One end of the tube was closed, so it could fill up with hot water, eliminating the need for constantly flowing water through it. It was modeled in SOLIDWORKS, and printed using the Phrozen Sonic Mini 4K SLA Printer. The tube had the following dimensions:

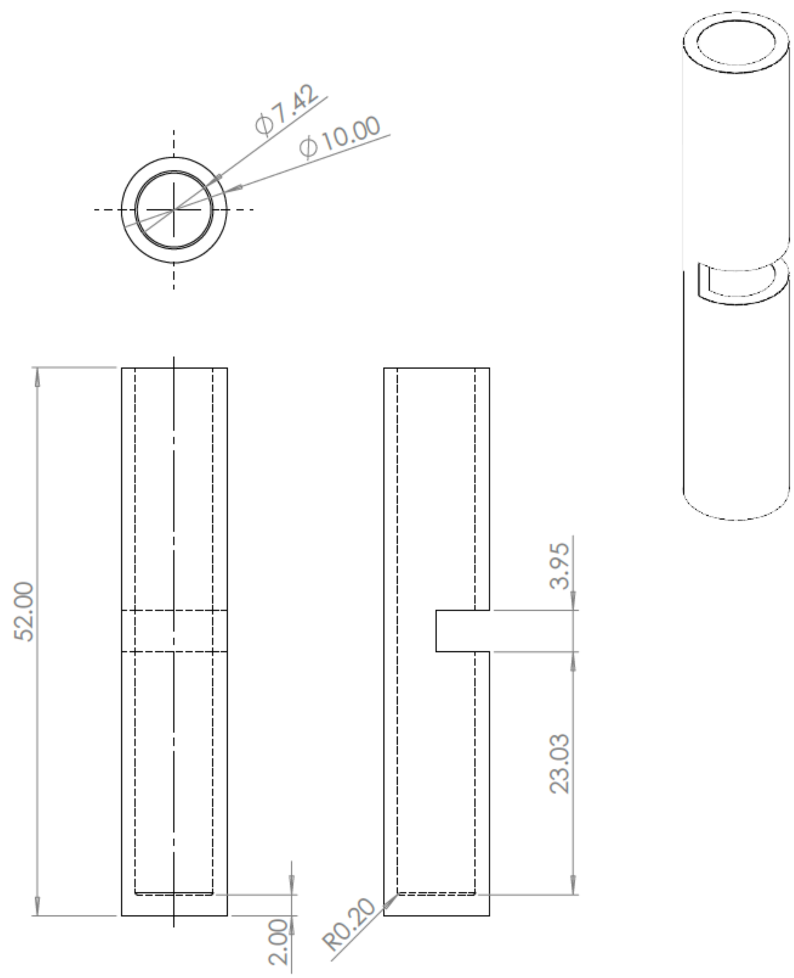

Figure 11: Drawing of the testing tube

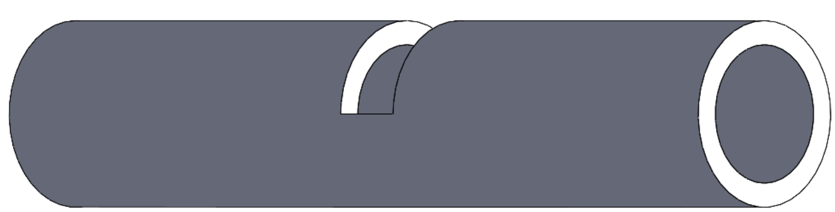

Figure 12: CAD Model of the testing tube

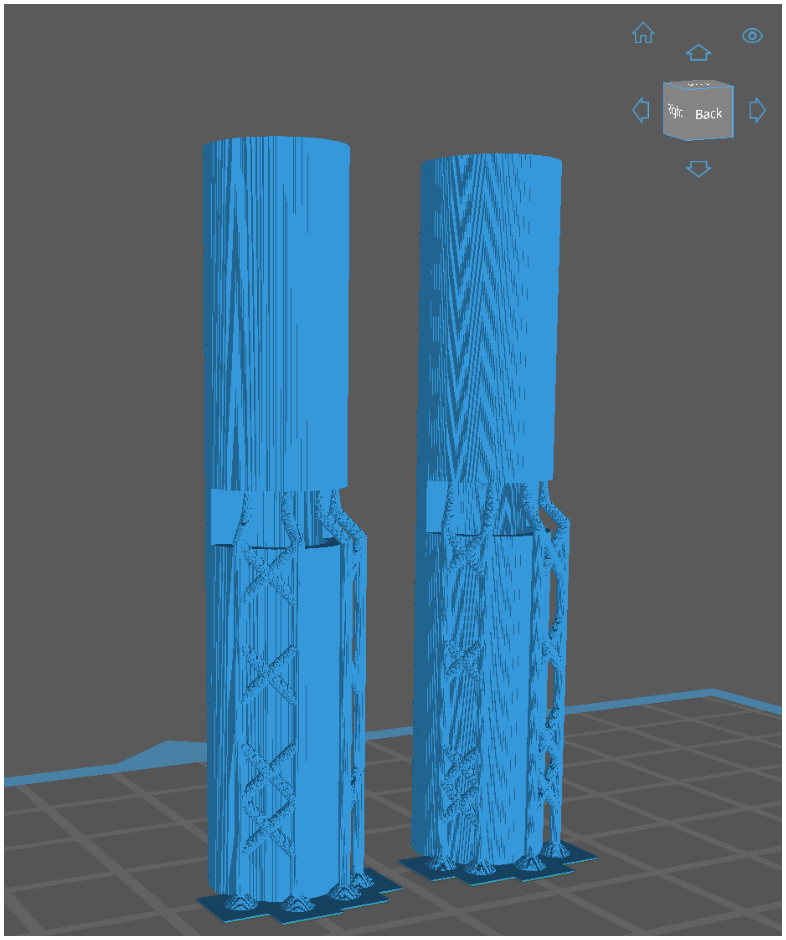

Figure 13: Supports added for overhang and slicing done using Chitubox

Electrical Circuitry used to test the TEG

The Initial electrical circuitry used to test the Thermoelectric Generation of the parts was very simple: it consisted of an LED connected to two terminals that would connect to either ends of the n-p-n-p junction of TE material. Once we could get this to work, we planned to move on to other, more complex electrical uses for the harvested energy. However, we were unable to go beyond this step due to some defects in the sintered TE parts (discussed in greater detail in the following sections).
The circuitry is shown below:

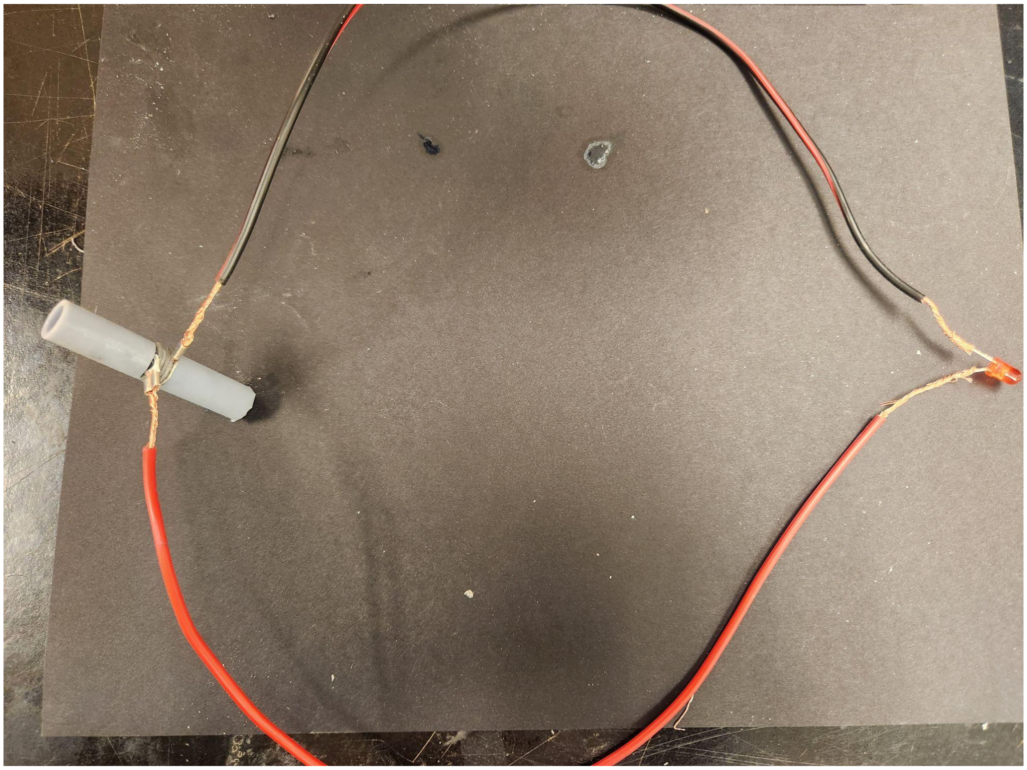

Figure 14: Test pipe connected to LED

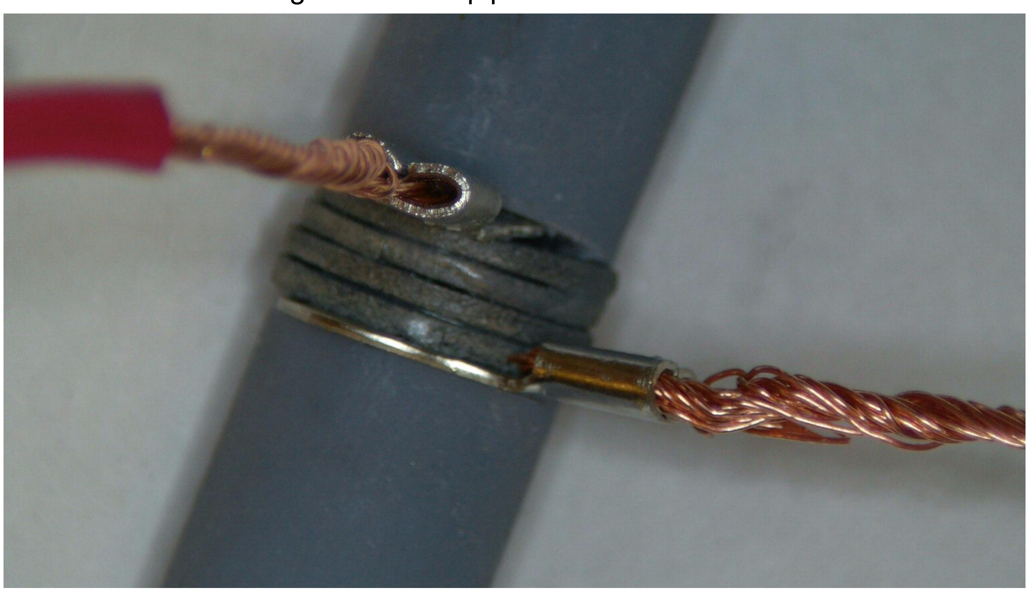

Figure 15: Magnified view of the n-p-n-p junction of TE Material connected to the tube

Equipment used in the Manufacturing Process

SLA 3D Printer

The Phrozen Sonic Mini 4K 3D printer was used to 3D print the molds, presses, and testing tubes. This is a Stereolithography (SLA) based 3D printer. A diagram of the basic working principles of SLA printers is attached.

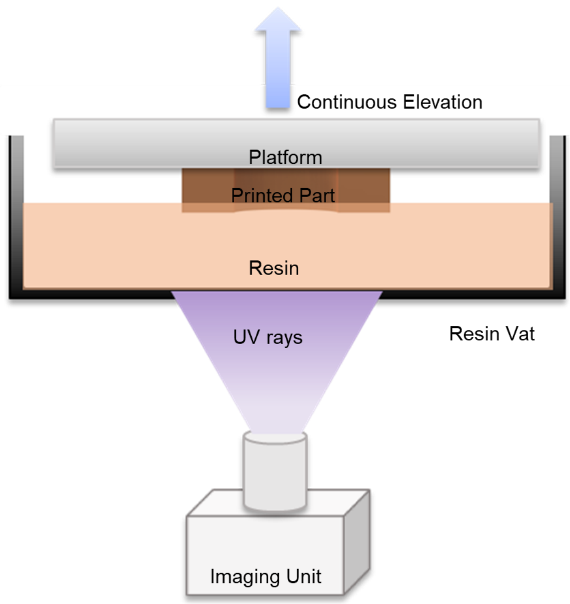

Figure 16: SLA 3D Printing Diagram [1]

Figure 17: The SLA 3D Printer we used

Hot Press

The hot press was used to heat and press the TE Material into the molds before sintering. We used a range of pressing forces and temperatures on different parts to study the effect of varying these parameters on the finished parts. The table of varied pressing parameters and the hot press are shown below:

Temperature (°C)	**Force 1**	**Force 2**	**Force 3**
Room Temp (~25)	Hand	40%	60%
75	Hand	40%	60%
150	Hand	40%	60%

Table 1: Pressing parameters (force is given as a percentage of 30 kg-force)

Figure 18: Hot Press

Arduino Pressure Sensor

While heat pressing the material into the molds, we used an Arduino Pressure sensor to measure the pressure, and hence pressing force we were applying through the heat press. The pressure sensor is shown below:

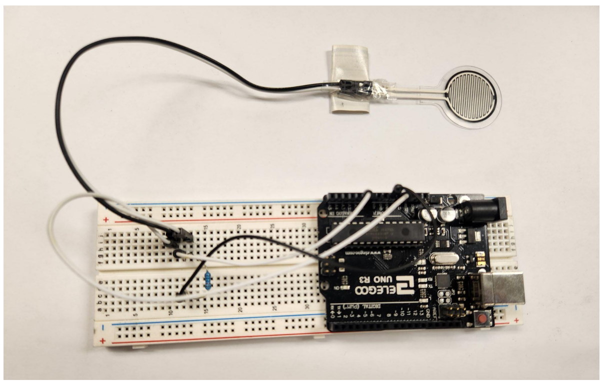

Figure 19: Arduino Pressure Sensor

Furnace

We used the KSL-1700X Furnace to sinter the parts. Sintering temperature was 400°C (See Figure 7 for the Sintering Curve).

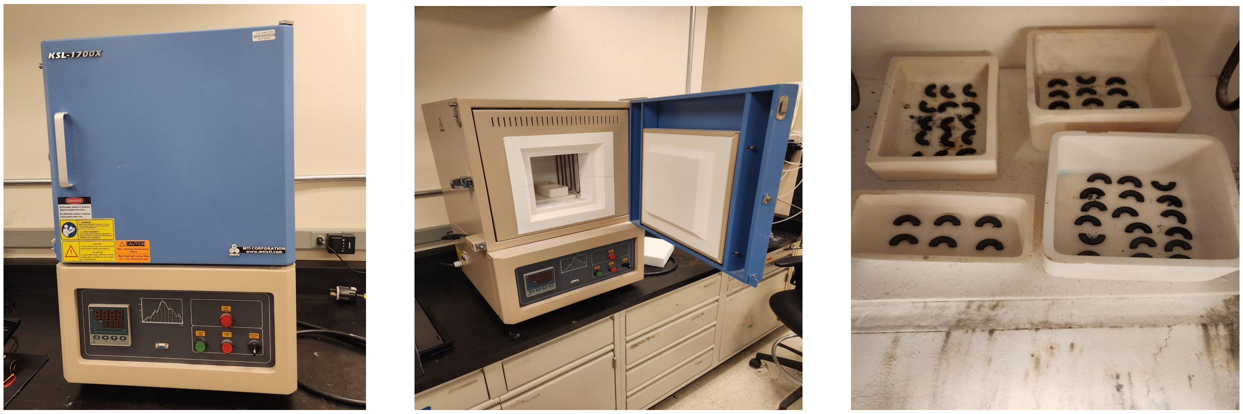

Figure 20: (a) & (b) The furnace, (c) Parts in the furnace after sintering

Ultrasonic Cleaner

After sintering, we observed a layer of surface impurities on the parts. We attempted to use the Ultrasonic cleaner to remove these impurities with both water and isopropyl alcohol (IPA). We did not have much success due to the thickness of the surface depositions.

Figure 21: Ultrasonic cleaner

Findings, Results, and Lessons Learnt

We the authors of this report found the MAE 598/494 class to be very engaging and informative. Throughout the class new discoveries were made on how mechatronic systems are integrated into today's everyday culture and how its improvements are propelling us into a better future. These improvements help in everyday tasks such as cleaning up the improvements in the medical field to help save lives. From this project alone we learned various lessons. This project has focused on the creation process of the hot water-waste harvest device and how it may be innovated.

The hot water-waste harvest device uses a TE device with thermoelectric generation to produce electricity from hot water. Common TE devices are planar structures made of n-p-n-p junctions. When used on a hot water pipe there is neglected space which causes heat loss and the thermoelectric generation to be inefficient. This project improves these TE devices by creating n-p-n-p junctions that are curved so that it might curve around a pipe for a more efficient thermoelectric generation of electricity. The building process of the curved n-p-n-p junction allowed us to interact with multiple mechatronic systems, such as the SLA printer and furnace.

The SLA printer uses a UV light to cure resin on a platform, which created our 3D printed molds and presses. When working with the SLA printer we discovered some of the molds were unusable. The top layers of the usable molds did not adhere well and peeled off, making the mold not able to hold the precise amount of the ground material. This may have been a result of UV light being obstructed. The obstruction could have been caused by the clear vac tank bottom plate not being fully cleaned, scratches on the bottom plate and the UV light not warming enough at the start. We learned to check that the SLA printer is working properly by cleaning the resin vat tank meticulously and watching the UV light to ensure it is on during the curing process. We also learned to make extras of the molds in case some molds are not usable.

The sintering furnace was employed to convert the ground N and P materials inside the molds into solid pieces through sintering. We learned the sintering process uses a sintering curve to steadily increase temperature and hold the temperature at prescribed temperature for an extended amount of time, and then steadily decrease the temperature. After completing this process, the sintered N and P parts were discovered to be non-conductive. They had large amounts of surface deposition of oxides as well as polymer ash, which made them non-conductive and unable to function in the n-p-n-p junction. These can be seen in Figure 22 below:

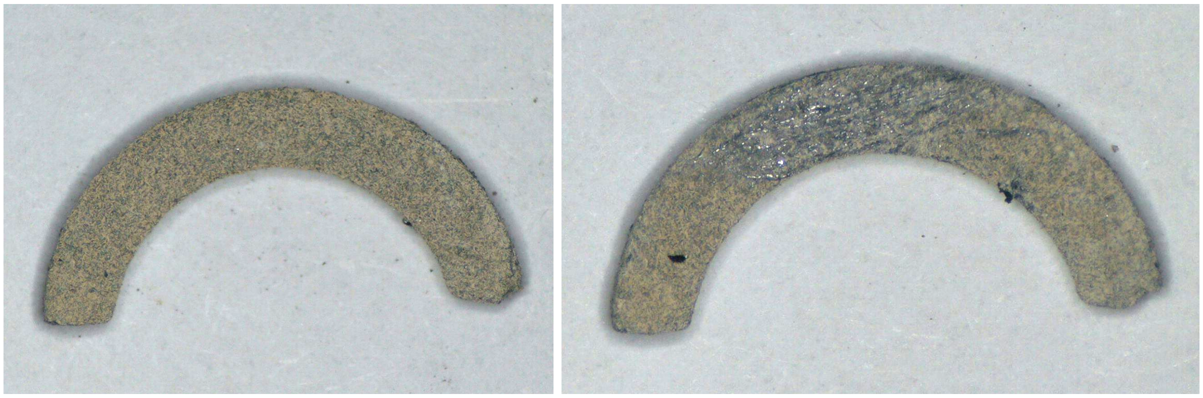

Figure 22: n-type part (a) after coming out of the furnace (note the yellowish surface deposits), and (b) after some of the surface deposits were scratched off to reveal silver colored TE material underneath

An ultrasonic cleaner was implemented in an attempt to clean the surface impurities off the component after the sintering process but did not remove the impurities. From literature we learnt that furnace sintering is not suitable for the particular TE material we used. **In future, advanced techniques such as laser sintering and plasma arc sintering can be employed to manufacture parts that are free from such surface impurities.**

References

[1] L. Tiwari, T. Tang, J. Rong, W. Shan, Y. Yang, and X. Li, “Thermoelectric material fabrication using mask image projection based stereolithography integrated with Hot Pressing,” *Journal of Material Science and Technology Research*, vol. 9, no. 1, pp. 105–113, 2022.

Appendix

A.1 Contribution Table

Application Project Contribution	
Contribution	Team Member(s)
Objective of application Project	Antonio Caputo
Basic Info of Building	Antonio Caputo
Basic Construction	Kenneth Dmello
Mechatronic System	Kenneth Dmello
Sub Functional Components	Tabsheer Askari
Electronic System	Tabsheer Askari
Conclusion	Desirae Perales
Evaluation Improvements	Desirae Perales