Abstract. This thesis aims to design a pipe-cutting machine using costume-made metal fixtures, an Avid CNC Bench Top machine, and Mach4 control software to cut strips off from pipes made of PVC, resin, and fibreglass materials automatically. The costume-made fixtures clamp down the pipe and rotate it to perform multiple cuts around it. Avid CNC Bench Top Machine is used to perform the ramping cut with a 10mm diameter square shoulder milling cutter. A touch probe is mounted beside the cutter to measure the accurate pipe diameter. An HMI (Human Machine Interface) that allows the operator to input the dimension of the pipe and perform calibration before use is developed using the LUA language under Mach4 motion control software. Screen and button scripts are programmed to read the input from the operator and sensors to generate a Gcode file to drive the CNC machine. The machine prototype can cut 5 strips in 30 minutes with the dimensions and surface finish required by ASTM D790 and ASTM D638, significantly increasing the production rate and reducing the waste of human resources while focusing on the environmentally friendly and cost-friendly for small businesses.

Keywords: ASTM Testing; PVC pipe; cutting machine; CNC

1. Introduction

In North America, a large amount of underground piping systems were built in the 1950s and 1960s. The piping systems back then were mostly made of cast iron. Canada has been investing in extending the life of the existing system since the 1990s [1]. Cured in Place Pipe has been chosen as a main solution due to its safety, efficiency, and cost advantages. In the quality control process of the trenchless installation technique, flexural and tensile properties of the pipes are tested to evaluate short-term performance and a creep test is performed to assess long-term performance [2]. According to the specifications of specimen dimensions sections in ASTM D790-10, Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulation Materials [3], ASTM D638-10, Standard Test Methods for Tensile Properties of Plastics [4], and ASTM D2990-09, Standard Test Methods for Tensile [5], Compressive, and Flexural Creep and Creep-Rupture of Plastics, all testing methods require the testing specimen to be cut into rectangular pieces.

The current methods for cutting the PVC and resin material include the following types: water jet cutting machine, planetary type cutting machine, and laser cutting machine. However, these cutting methods are not suitable for CIPP specimen preparation. The water jet cutting method will leave the nonuniform cutting gap and significant burrs [6], which will significantly affect the result of the bending test and tensile test due to the change of the cross-section area. Besides, water jet cutting machines usually require a large set-up space, which is not friendly to small businesses. Planetary cutting machines usually use the circular saw blade, which can only cut the pipe into large pieces radially or axially [7]. From the experiment result produced by the technician, this method wastes a large amount of materials and does not give any redundancy to prevent operation error. The laser cutting technique gives a better surface finish but produces toxic gas emissions, which may violate local environmental laws, and eliminating the pollution is costly [8].

This article will introduce a prototype of an automated specimen preparation machine that requires minimum input and operation from the operator and simplifies the test specimen preparation process. The HMI of the machine will take the measurement and the material of the pipe as input from the
operator. The dimension of the test specimen will be calculated automatically by the control program. The touch probe can automatically measure the accurate diameter of the CIPP pipe at different locations and generate a Gcode file for the CNC machine to perform the cutting process. The design will be explained in three parts: the pipe clamping system, the CNC machine cutting system, and the control program.

2. Design Details

2.1. Research Intent

The most common fabrication process in the CIPP quality control industry is first to separate the PVC layer and the liner layer (see Figure 1). Then, cut the pipe into five evenly distributed portions along the axis of the pipe using a bandsaw (see Figure 2). Finally, a milling machine is used to cut the sample into the right size and machine the inner and outer surfaces flat (see Figure 3). The manual process for one pipe sample usually takes 3 to 4 technicians working 1 hour to complete, which is time-consuming and has potential safety hazards when using the bandsaw and the milling machine. Also, the production quality of the existing process heavily relies on the technicians’ familiarity with the procedure, and there is limited fault tolerance since most of the pipe material is machined off. Therefore, the need to design an autonomous machine to complete the specimen preparation process with minimal human interaction and maximum efficiency is promoted. Finally, Figure 4 and 5 showed the overview of the cutting machine and specimen cut using the prototype machine, respectively.

![Before removing PVC](image1.png) ![After Removing PVC](image2.png)

**Fig1.** Manual Process Step #1 - Removing PVC (photo credited: original).

![Manual Process Step #2 Cutting Liner](image3.png)

**Fig 2.** Manual Process Step #2 Cutting Liner (photo credited: original).

Fig 4. Overview of the Cutting Machine (photo credited: original).

Fig 5. Specimen cut using the Prototype Machine (photo credited: original).
2.2. Measure Process

A touch probe is attached beside the cutter to measure the actual diameter of the pipe. The Keyence GT2 series touch probe is selected. If the probe is directly used on the liner, which is usually an isotropic cylinder shape, the top surface of the sample can also be machined during the process since the accuracy is as small as 1um [9]. On the HMI, Length of the Pipe, Diameter of the pipe, liner thickness and PVC thickness are required as input. However, the diameter may fluctuate for the following reasons: firstly, the PVC pipe may not be a perfect cylinder shape; secondly, there is typically resin residue present on the outer wall of the PVC, as shown in Figure 6; and thirdly, the clamping force can cause deformation in the pipe.

![Image of resin residue on PVC](photo credited: original)

**Fig 6.** Resin residue on the outer wall of the PVC (photo credited: original).

The touch probe is designed to measure five points evenly distributed across the specified width of the specimen, as shown in Figure 7. The measured distances will be used to identify the position with the largest diameter along the X-axis and Z Axis and set it as the middle reference point of the specimen. In the case where resin residue is left on the surface, the measured data will have a more significant difference among the five data points. The program will automatically know the abnormal data points and calculate the average of the rest points as the actual diameter. This calculation's result may have an error of ±1mm but can be ignored since each cut depth will be 3mm. If the pipe is deformed for either reason mentioned above, the point where the max measured diameter will be used as the middle point of the specimen. Hence, the five-point measurement will maximally reduce the effect of the resin residue and the deformation of the pipe.

![Image of five-point measurement](photo credited: original)

**Fig 7.** Five-Point Measurement (photo credited: original).

Next, the stepper motor under the clamp will rotate the pipe to the next four positions and repeat the measuring process. The overall process of the work cycle is shown as Figure 8.
### 2.3. Cutting Process

The cutting process is executed by the Avid CNC Machine. A 10mm end milling cutter is used, which can help reduce the tool cost since the operator can only change the insert instead of the entire cutter. The cutter in Figure 9 is the one that has been used to cut 20 pieces of specimen, where the uncured resin left a mark on the stem of the cutter. Inserts in Figure 10 are the replacement inserts installed on the cutter after the existing one is worn out. The life of the inserts is still unknown since the current ones are still evaluated as sharp enough.

![Endmill Cutter with inserts](photo credited: original)

*Fig 9. Endmill Cutter with inserts (photo credited: original).*

![Replacement Inserts](photo credited: original)

*Fig 10. Replacement Inserts (photo credited: original).*

Avid CNC machine is driven by Gcode, therefore, the control program needs to generate a Gcode file. The cutting strategy is to first cut through the two sides and then mill down the top and bottom ends of the specimen to allow the operator to cut off the specimen easily. Specimens in Figure 11 represent the finished product where the PVC layer has been removed.
Fig 11. Representative photo of the Finished Specimen (photo credited: original).

The through cut on the two sides used a ramping cut method, starting from the origin and cutting diagonally down until the ramping depth, shown as Figure 12. The ramping depth limit set by the specification of the cutter is 6mm, but after the experiment of different combinations of ramping depth and feed rate, the optimal ramping depth is set to 3mm to avoid leaving cut marks on the sides. And, Figure 13 showed cut mark on the sides of the specimens.

Fig 12. Ramp Cut Path [10].

Fig 13. Cut mark on the Sides of the Specimens (photo credited: original).

The mill-down process will cut through until half of the liner thickness to reduce the thickness that needs to be manually cut off and leave the safe area to cut for the operator.

3. Result

The scope of the project was to reduce the CIPP pipe specimen preparation time from 1 hour per pipe to a shorter time. The machine successfully shortened the production period to 15 minutes per
pipe while the surface quality of the finished specimen was kept the same as the manual method. A complete Solidworks model was built, and a process of assembling the machine was developed for duplicating more machines in the future. An operation manual was also developed for the operator to operate the machine, perform routine calibration, replace worn parts and troubleshoot common errors. The first prototype has been thoroughly tested at the component and system levels to ensure the operation's functionality and safety. Instead of using three technicians to complete the sample preparation process as mentioned in 2.1, only one technician is required to operate the machine and the entire process is reduced to two steps. Efficiency and human resources have been utilized, and the testing lab's turnover rate has doubled.

4. Conclusion

Improvements in the machine are still ongoing to adapt to more pipe diameters and materials such as fibreglass and carbon fibre. The difficulty of adapting different materials is determining the suitable feed rate and the RPM of the CNC cutter. Since the machine is still a prototype, there is space to simplify the assembly process for rapid manufacturing and reduce cost. One of the improvements can be made is the dust collection system. CNC machining resin can generate a massive amount of dust emission. The current solution is to adjust the feed rate and the RPM to create larger chips and attach a high-power vacuum and dust shoe to the cutter. The design can eliminate most of the dust but still cannot guarantee zero emission. Another future research area is to design a second machine to process the fourth side of the specimen. The overarching objective of this project is to design robots that can fully replace the manual process. Since three sides are machined to the required surface flatness using the current machine. The final step will entail machining the remaining side.

References