

Effect of Cutting Parameters on Performance of CNC Hot Wire styrofoam Cutting Machine

Md Soad Solaiman

Industrial and Production Engineering Department
Military Institute of Science and Technology
Dhaka, Bangladesh
soadsolaiman28@gmail.com

Md Sakibul Islam Sakib

Industrial and Production Engineering Department
Military Institute of Science and Technology
Dhaka, Bangladesh
mdsakibulislam999@gmail.com

Md. Arifur Rahman

Industrial and Production Engineering Department
Military Institute of Science and Technology
Dhaka, Bangladesh
rahmanarifur1308@gmail.com

Adib Bin Rashid

Industrial and Production Engineering Department
Military Institute of Science and Technology
Dhaka, Bangladesh
adib@me.mist.ac.bd

Abstract

Styrofoam, or expanded polystyrene foam (EPS), is commonly used for packaging fragile items, insulation in construction, disposable food containers, crafting, and art projects. Its lightweight and insulating properties make it versatile. Additionally, it is used in floatation devices, horticulture, and construction formwork. Manual styrofoam cutting presents several challenges, including inaccurate cuts, rough surfaces, difficulty achieving consistency and precision, time-consuming processes, increased material wastage, and safety concerns. Automation through CNC machines, like the CNC Styrofoam Cutter, addresses these issues by providing precision, consistency, and efficiency in handling complex designs, offering a controlled and reliable solution for cutting styrofoam. Hotwire mechanism is used in this CNC machine to cut the Styrofoam. This paper analyses the relation between the supply current on the wire, kerf width of the cut, cutting time, and temperature variations during cutting to get the optimum cutting parameters.

Keywords

Styrofoam, CNC Hotwire, Kerf width, EPS, Cork sheet, Automated foam cutting, Corksheet cutter, Optimization.

1. Introduction

The industry is continuously developing. For example, Styrofoam decorations can be used in various things, such as placards, artwork, safety goods on shipping, etc. Using CNC Wire Cutter to make decorations will shorten the time needed (Sulkowski et al. 2009). In order to forecast and compute the surface roughness (Ra) and kerf width

using a mathematical model, a researcher conducted the ablation process for Expanded Polystyrene (EPS) rapid prototyping (Fahrizal et al. 2023). A unique thermos electro-mechanical model for hotwire cutting of EPS foam was proposed by a model that predicts the temperature, voltage, and stress of the wire throughout the cutting process (Memon et al. 2023). With the advancement of technology, CNC machines have also evolved and allow greater flexibility in production since they can produce increasingly complex parts with greater detail. Many Styrofoam craftsmen in Indonesia use manual Styrofoam cutting tools, namely cutters and hot wires (Wijaya et al. 2017). The cutting of Styrofoam using hot wire is widespread. However, the cutting parameters should be optimized to get an economical workflow for the Styrofoam with the least roughness of the surface and kerf width. This paper analyses the effects of cutting parameters on the performance of “CNC hot wire Styrofoam cutting machine” to get the optimized parameters, especially the optimum input current flow.

2. Literature Review

The industry's development is rapidly expanding. For instance, Styrofoam can be used to make decorations for various purposes, such as creating art, advertising, shipping safety goods, and even more. Since CNC machines can produce increasingly complex parts and ensure uniform cuts, which offer consistent results across several pieces, they have advanced along with technology, allowing for increased production flexibility (Syahriza et al.2020). Nowadays, many Styrofoam craftsmen in Indonesia utilize cutters and hot wire, which are manual Styrofoam cutting tools (Wijaya et al. 2017). A well-organized hand Styrofoam cutting process requires several auxiliary tasks, including measurements, sketching, and more. Making perfect cuts by hand is difficult since it greatly depends on the operator's ability to keep steady hands and precise angles. The ingenuity and adaptability of foam applications may be limited by manual cutters' inability to readily handle elaborate shapes or complex designs (Ninawe et al. 2021). It will be difficult to cope with the numerous products requested in various shapes since it calls for focus on cutting, dimensions, and sketches (Cheng 2012).

Foam cutting is traditionally accomplished by hand using a cutter or a hotwire. Abilities are needed to cut accurately to achieve an excellent surface quality (Aitchison et al. 2007). This foam cut aids in the designer's analysis of challenges, gives parameters for restating the design and assesses the model's performance in real-world scenarios. The foam model is regularly tried and tested to produce the most effective results. Prototype creation is a time-consuming and labor-intensive process. When employing manual techniques, the prototype process can be time-consuming and labor-intensive. Additionally, it can be difficult to choose the right materials for prototyping because some might not be easily accessible or appropriate for the intended use (Petkov & Hattel, 2016). Time is also the most important factor in research and development. Hotwire cutting is the most effective method for cutting plastic foam since it is created by casting and extrusion. Applying heat through wire can change the material's physical properties to the point where cutting requires less force (Stege 2011).

Numerous experts have looked at the effective parameters and cutting procedure of polymers. The impact of polymer cutting process parameters on material removal rate, kerf width, and machining process optimization was investigated by Harmanpreet & Manpreet Singh (Dhinesh et al. 2021.). The relationship between the cutting angle taken from the horizontal direction and the kerf width must also be determined. Variations in material properties, such as density and thermal conductivity, can also affect kerf width. Different materials respond differently to the heat the wire generates, leading to cut quality variations and kerf width variations(Aitchison et al. 2009.).

In addition to building more accurate prototypes and examining kerf width, some factors causing the bowing phenomenon are looked at through experiments involving variations in current and wire feed rate (Mohammed and Kadhum 2019). An empirical relationship is established to predict the surface roughness (Ra) of the sliced surface by performing regression analysis (Universitas Gadjah Mada et al. 2017). A numerically controlled foam cutter must be able to cut complex shapes out of foam material, such as extruded polystyrene, by using a 3D virtual model. A novel mathematical model must also predict the Kerf width (Syahriza et al. 2020). The impact of process parameters, such as cutting angle and expandable polystyrene compositions, on the surface roughness of hotwire of variable lamination manufacturing (VLM-S) for EPS foam was investigated using a four-axis automatic cutter and thin foam as the specimen (Ahn et al. 2023).

To solve this problem, CNC CORK Sheet Cutter is used as a substitute for cutting tools made of cutter blades, multiplex saws, or similar tools, which are inappropriate for cutting results compared to CNC Wire Cutter tools. The CNC CORK Sheet cutter's working principle is converting electrical energy into heat energy. This CNC Wire Cutter already uses numerical control using CNC programming, and the cutting precision is much faster. Wire Cutter CNC machine can cut as designed by CAD drawing modules that work automatically with G-code input from the computer. Thermo-mechanical cutting a mixing between the shearing force and the melting of material to perfume the cutting and the hot-tool in contact with the material (H. Brooks 2009). See Figure 1 (a).

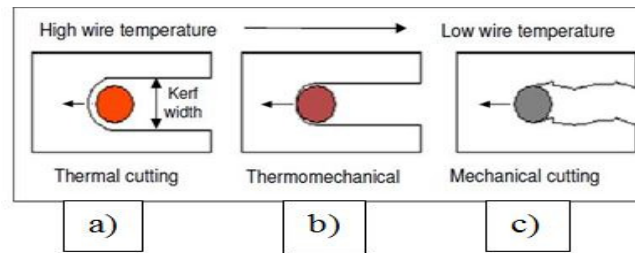


Figure 1. (a). Cutting mechanisms

3. Material and Method

3.1 Material

The machine's components are probably durable materials that can survive cutting, as the equipment is meant to cut foam sheets. When current is passed through resistance wire, which the machine uses to cut foam, it becomes extremely hot. Thus, the wire needs to be able to withstand heat. The Nichrome Wire was chosen to cut the foam. Since it was between Tungsten and Nichrome Wire, the Weighted Average Method was used to choose the wire. Furthermore, a portion of the machine was 3D printed, while most of the body was aluminum. Aluminum T-slot 20x20mm profiles are used in the base construction. A few criteria were considered when choosing these materials: performance, cost, and availability.

3.2 Black Box Diagram

A black box is a system that can be viewed in terms of its inputs and outputs (or transfer characteristics) without knowing its internal workings. There are generally three types of input and corresponding output in a black box. They are energy flow, material flow, and information flow which is figured in figure 1 (b).

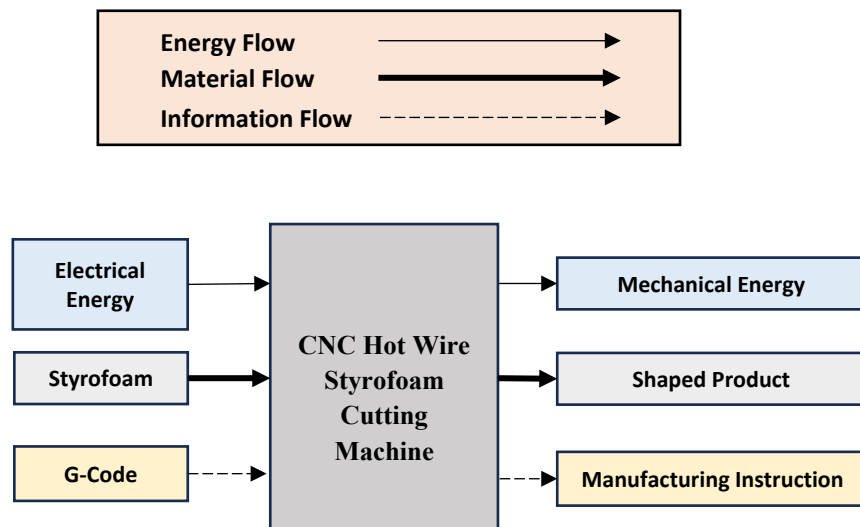


Figure 1. (b) Black Box Diagram

3.3 Cluster function

Cluster function structure, shown in Figure 2, describes the processes involved with individual features in a step-by-step manner. Cluster analysis requires cluster functions. They facilitate the discovery of patterns and grouping of related data pieces, providing insights into the data's structure. This is useful for tasks like pattern identification, anomaly detection, and consumer segmentation. They facilitate efficient resource allocation, fault tolerance, and load balancing among cluster nodes. Maintaining system performance and stability depends on this.

3.4 Method

This research aims to develop a more precise and quick foam-cutting technology that requires less labor and physical skills. This machine uses a hot wire cutting technique on a CNC machine to cut foam precisely and intricately. The foam is sheared at a temperature lower than its melting point as part of the thermomechanical cutting process. In order to make the machining process safe and user-friendly, ergonomic design concepts are implemented, taking into account things like the product's appropriate weight and size. To enable accurate and

automated cutting, the machine's hot wire is moved under control by a CNC (Computer Numerical Control) system. Two motors provide the power to rotate the machine in the X and Y axes. Additionally, pulleys aid in the motor's ability to rotate the machine. The cutting wire is linked to a spring with the machine. This is necessary because the wire will lengthen when heated, and the springs can compensate for it. This is why the wire needs to be tensioned this way with springs. To get a detailed visualization, the components hierarchy of CNC Styrofoam is shown in Figure 3. Also, the CAD design and the machine is shown in Figure 4(a) and (b). Furthermore, table 1 describes the specifications of the machine.

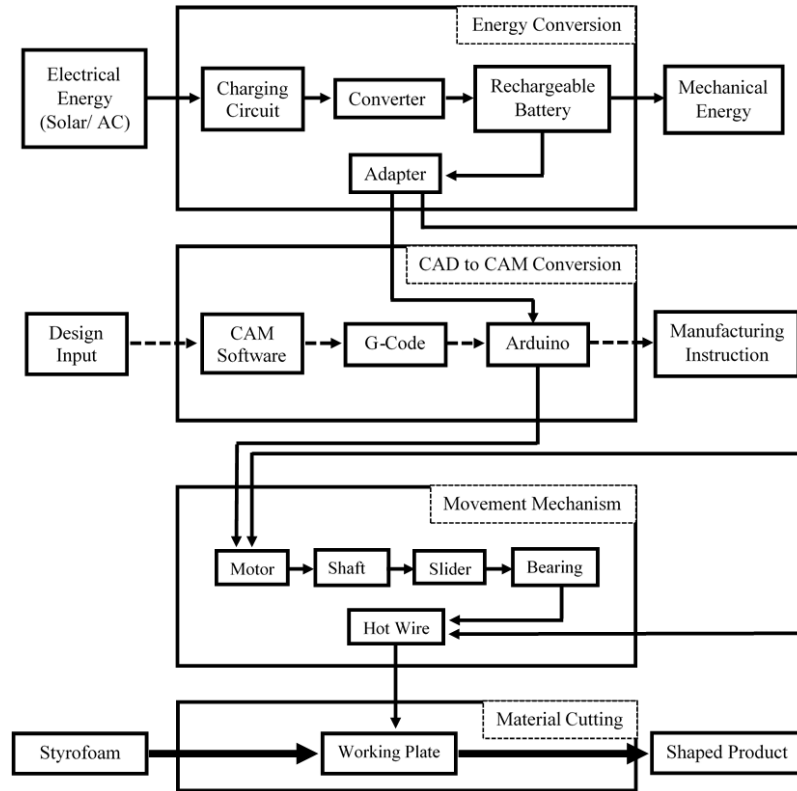


Figure 2. Cluster Function

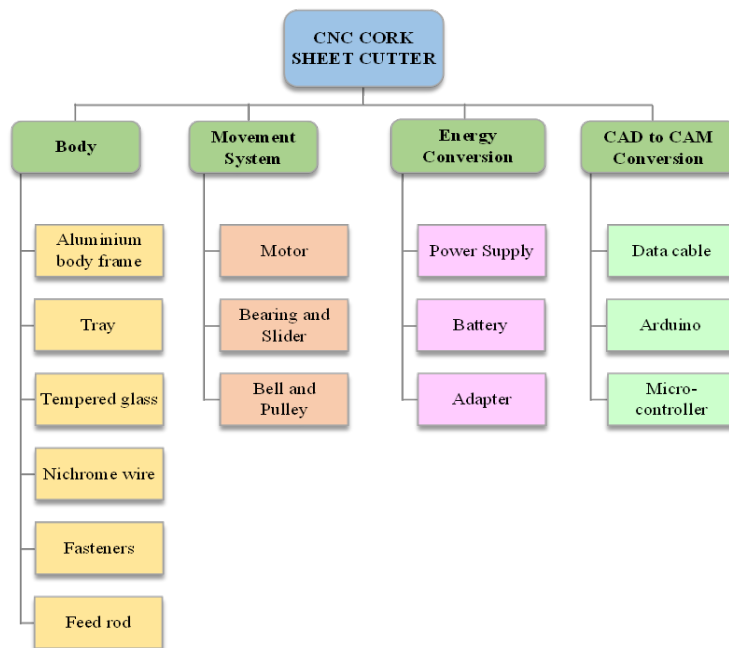


Figure 3. Components hierarchy of CNC Styrofoam or Cork Sheet Cutter

Table 1. Specifications of CNC Hot Wire Styrofoam Cutting Machine

No	Specifications	Values/Materials
1	Dimension (Length*Width*Height) (Inch)	20*20*15
2	Weight (Kg)	3.65
3	Body Structure	T-Slot Aluminum Profile
4	Rails	SS Shaft
5	Hot wire	Nichrome Wire
6	Brackets, Sliding blocks (Vertical and Horizontal)	3D printed of PLA Material
7	Motor	Stepper Motor Nema 17 (14 W)

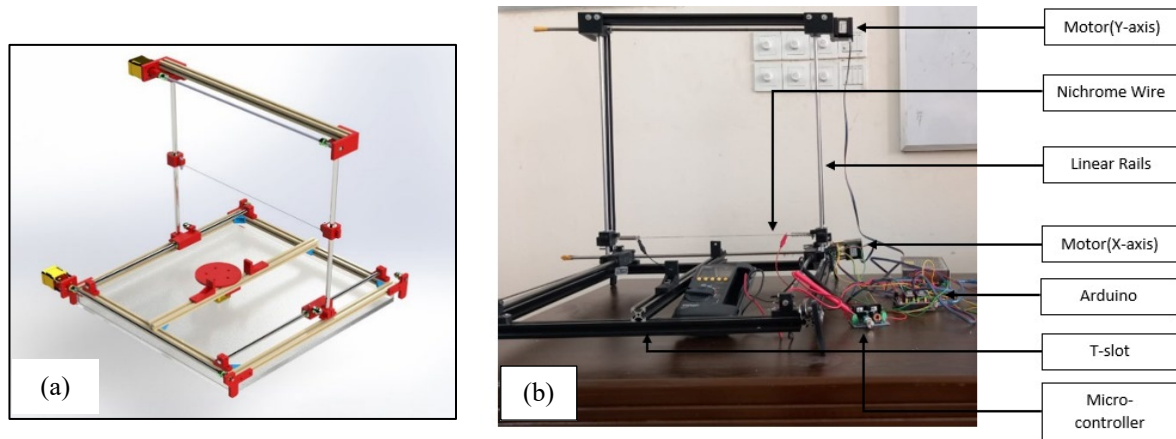


Figure 4. (a) CAD Design of CNC Styrofoam Cutter (b) CNC Styrofoam Cutter

3.5 Circuit

An Arduino board serves as this CNC machine's brain. We also require a DC-to-DC converter, two stepper drives, and an Arduino CNC Shield to regulate the hot wire's temperature. Both stepper motors are connected to the Arduino CNC shield, and the two limit switches are connected to the X+ and Y+ end stop pins. Three connections are available on these micro limit switches: ground, normally open, and normally closed. After some testing, it was attached to a typically closed connection because the machine operates more steadily. On the input of the DC Converter, a switch is added so that it may be used to turn the hot wire on and off individually. Two wires from the resistance wire's (Nichrome Wire) two ends were linked to the DC converter's output. A visualization of how to get a circuit connection is given in Figure 5.

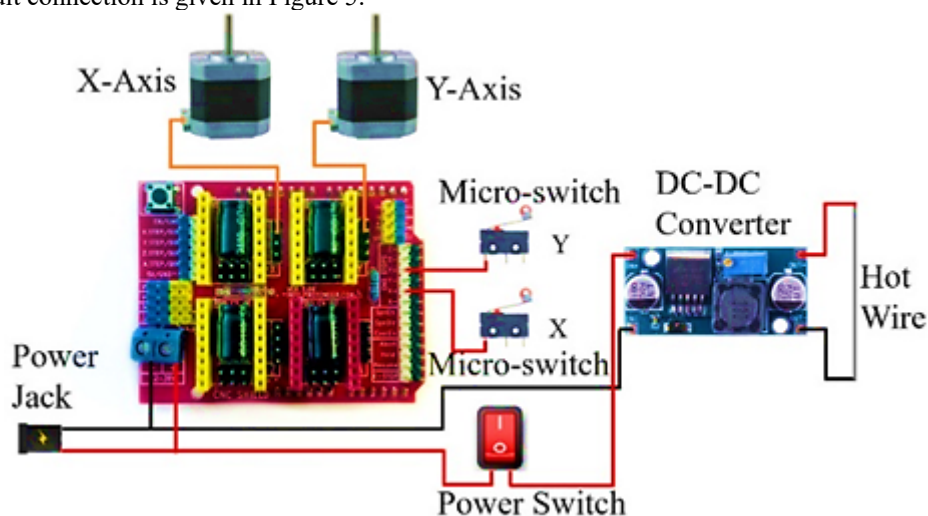


Figure 5. Arduino CNC Circuit Diagram

3.6 Softwares

A firmware that regulates the machine's motion must first be uploaded to the Arduino to function as a CNC machine. The firmware used here is GRBL. Then we connected it with the Arduino. Once connected, the Arduino can read G-codes and direct the machine according to them. Arduino then requires an interface or controller to provide commands. Universal G-Code Sender is the software that is used. To configure the system, open the Universal G-Code Sender program and launch the Setup wizard. Here, we must select the proper port and connect the program to Arduino. Also, the motors' steps must be calibrated to achieve correct and accurate movement. Instruction flow in CNC Styrofoam Cutter can be visualized in Figure 6.

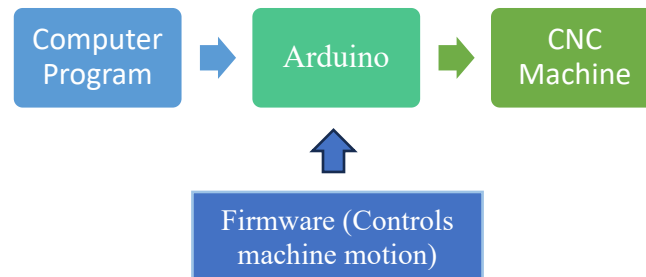


Figure 6. Instruction flow in CNC Styrofoam Cutter

3.7 Generating G-code

Inkscape is employed as vector graphic software in the initial design development stages. The software, characterized by its vector graphic capabilities, uses the Trace Bitmap function to convert any picture into a vector format. The subsequent transformation of the shape into a continuous path, imperative for the capability to cut any shape with the hot wire, is now necessitated. Unlike in laser machining scenarios, the cutting tool cannot be raised or switched off during the cutting process, as the wire remains consistently present in the designated area. Upon completion of the design, the production of G-code is facilitated by applying the extension of G-code tools. This extension plays a pivotal role in generating G-code, a set of instructions that can be interpreted and utilized by the Arduino or GRBL for the precise control of stepper motors. The procedural steps following the design phase involve scaling the model and creating orientation points. After scaling, the subsequent definition of cutting tools for the Arduino CNC machine becomes imperative. Notably, altering the cutting tool's parameters is a viable option for customization to specific project requirements. Following the meticulous setup, the path to G-code function is employed, leading to the generation of G-code that encapsulates the design instructions. The G-code thus generated serves as the guiding language for the Arduino or GRBL, orchestrating the precise movements of the stepper motors during the fabrication process. Upon opening the G-code in the Universal G-code Sender, the Visualizer window becomes instrumental in allowing the observation of the path the machine is intended to take. This step is crucial for ensuring precision in the execution of the design, providing a virtual preview of the fabrication process.

In summary, the design process involves the utilization of Inkscape's vector capabilities and the extension of the G-code tools for the generation of G-code. The subsequent stages, encompassing scaling, orientation points, and cutting tool definition, are pivotal for achieving a seamlessly executed design on the Arduino CNC machine, orchestrated by the interpreted G-code instructions. Figure 7 shows here the simple view of the flow of G-Code. Also, the top screen of Inkscape software and the UGS are shown in Figure 8 and Figure 9, respectively.

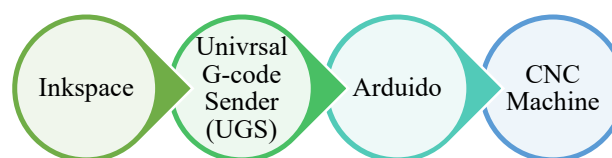


Figure 7. Flow of G-code

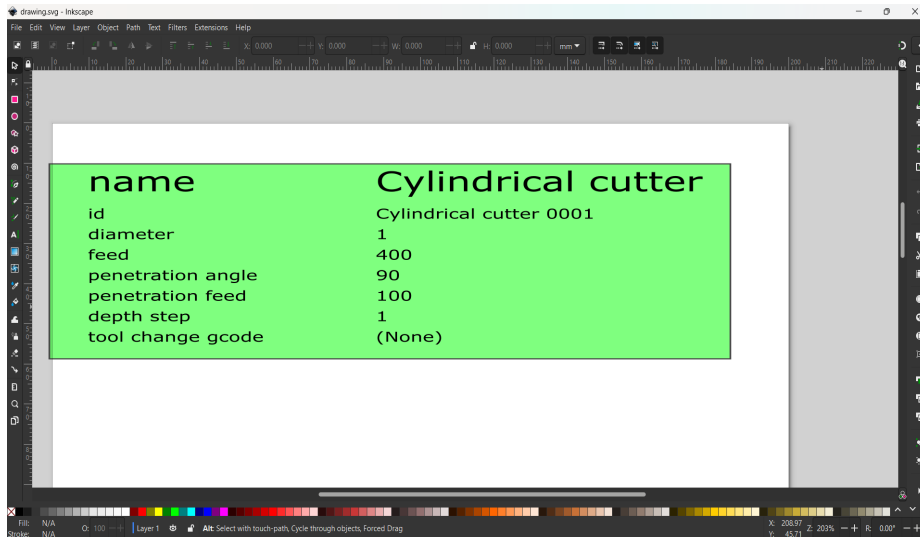


Figure 8. Inkscape Software

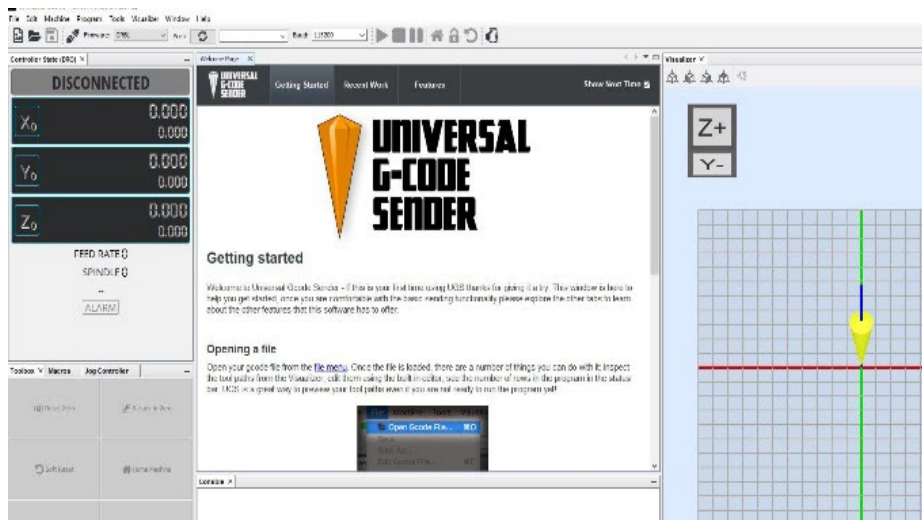


Figure 9. Universal G-code Sender Software

3.7 Measuring Instruments

Optical Microscope: An optical Microscope of Olympus Company with 10x view the kerf width is measured. In figure 11, the kerf widths are shown for the visualization.

Thermal Camera: UNI-T UTi260A Handheld Infrared Thermal Imager Camera to measure the temperature of the wire. The working temperature range is measured here (82.5°C – 150.5°C). Temperature fluctuations on different current flow are shown in figure 13.

Multimeter: Fluke 117 is used here to measure the current flow through the wire. The working current flow range is (0.45A-0.60A).

Stopwatch: Extech stopwatch is used here to measure the cutting time of the operation. Along with the stopwatch, all measuring devices are shown in figure 10.



Figure 10. Measuring instrument.

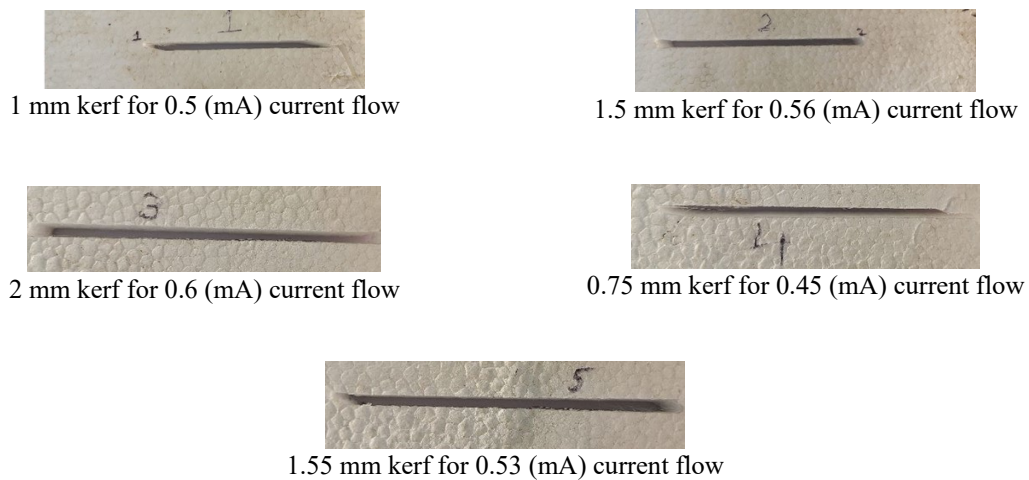


Figure 11. Kerf width on different current flow

4. Result Analysis

Regarding the wire's supply current (mA), the response of the kerf width (mm) and cutting time (sec) is noted. Figure 11(a) shows that the kerf width grows as the current value increases from 0.45mA to 0.6mA. This is due to the increasing current flow, which also increases the temperature of the wire. Thus, the foam's temperature rises fast and gets to the vaporization point, increasing the kerf width. There is a higher kerf width increment rate in 0.53mA. It's the wire's U-turn point (Figure: 11(a)) where the wire speed decreases. Thus, the contact time increases, and that's why the kerf width increases. Also, Figure 11 (b) shows that the cutting time gradually drops, and the cutting becomes smoother as the current flow increases. The current flow here generates the heat of the wire. As it increases, the temperature of the wire will increase. Thus, the foam vaporizes fast, and their friction decreases gradually. That's why cutting time decreases.

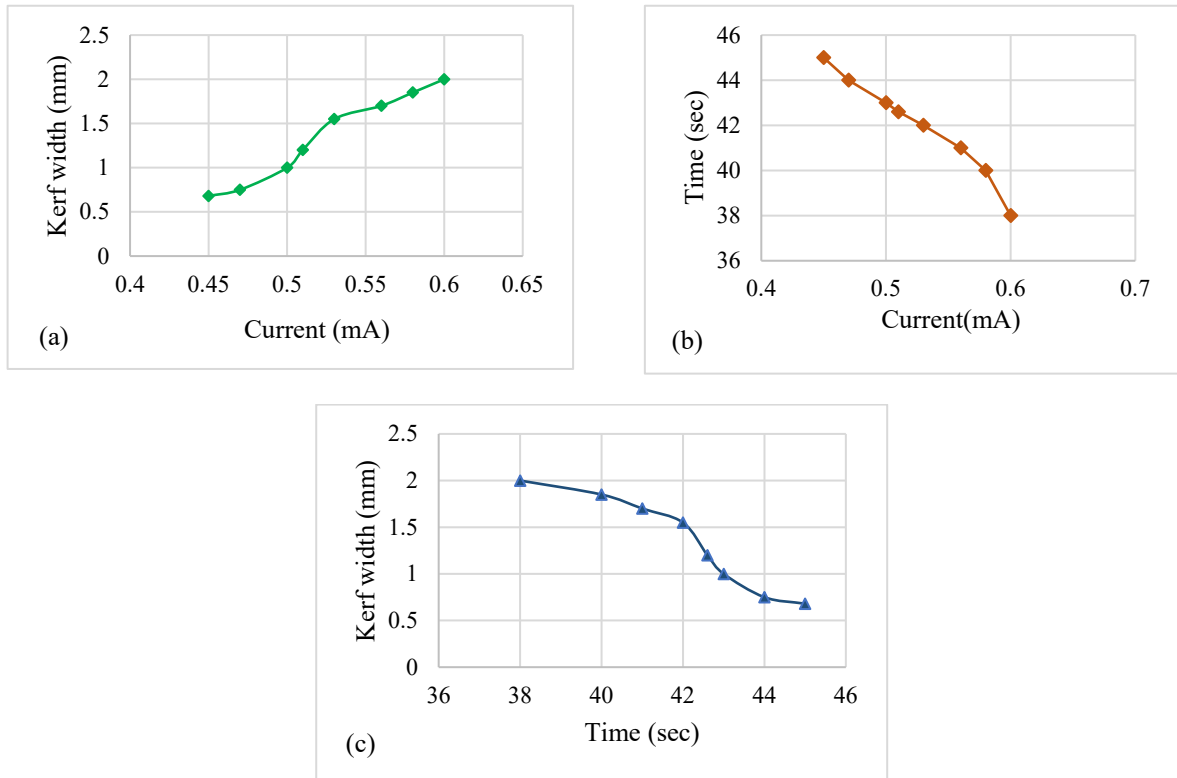


Figure 12. (a) Scatter diagram of Kerf width (mm) vs Current (mA); b) Curve of time (sec) vs current (mA) c) Curve of kerf width (mm) vs Time (sec)

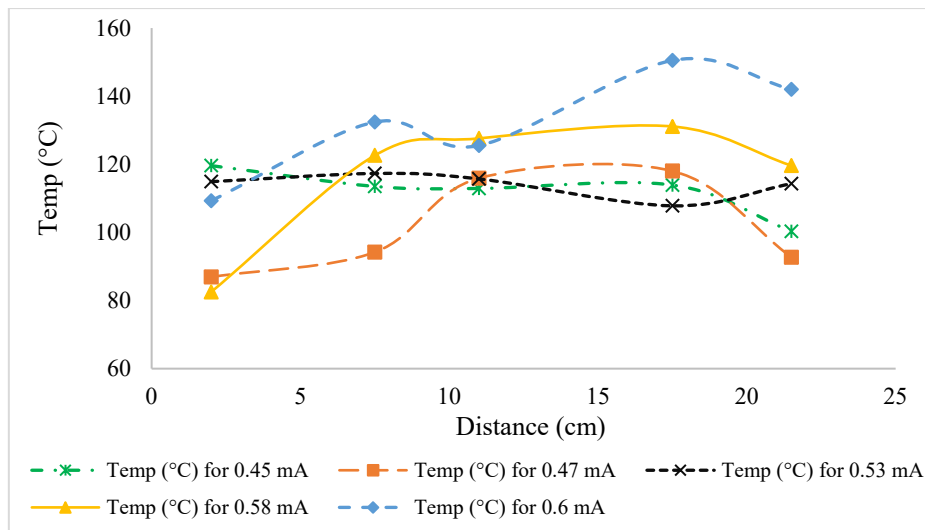


Figure 13. Curve of temperature (°C) vs distance (cm)

Once more, figure 12(c) appears to indicate that the kerf decreases with increasing cutting time. As a result, the 0.53mA–0.56mA is the ideal cutting zone, where the experiment's good cut is produced by a kerf width and cutting time that both stay considerable. From Figure 13, it is clear that at 0.45mA current the temperature fluctuation is the lowest, but the cutting time is high here as the friction is the highest and thus the surface smoothness is the lowest. On the other hand, 0.53mA current flow shows the nearest least fluctuation of the temperature where the cutting time is comparatively low as the friction is low, and thus, the surface smoothness is fine here. For other temperatures, the temperature fluctuation is high. Thus, it affects the kerf width and surface of the foam.

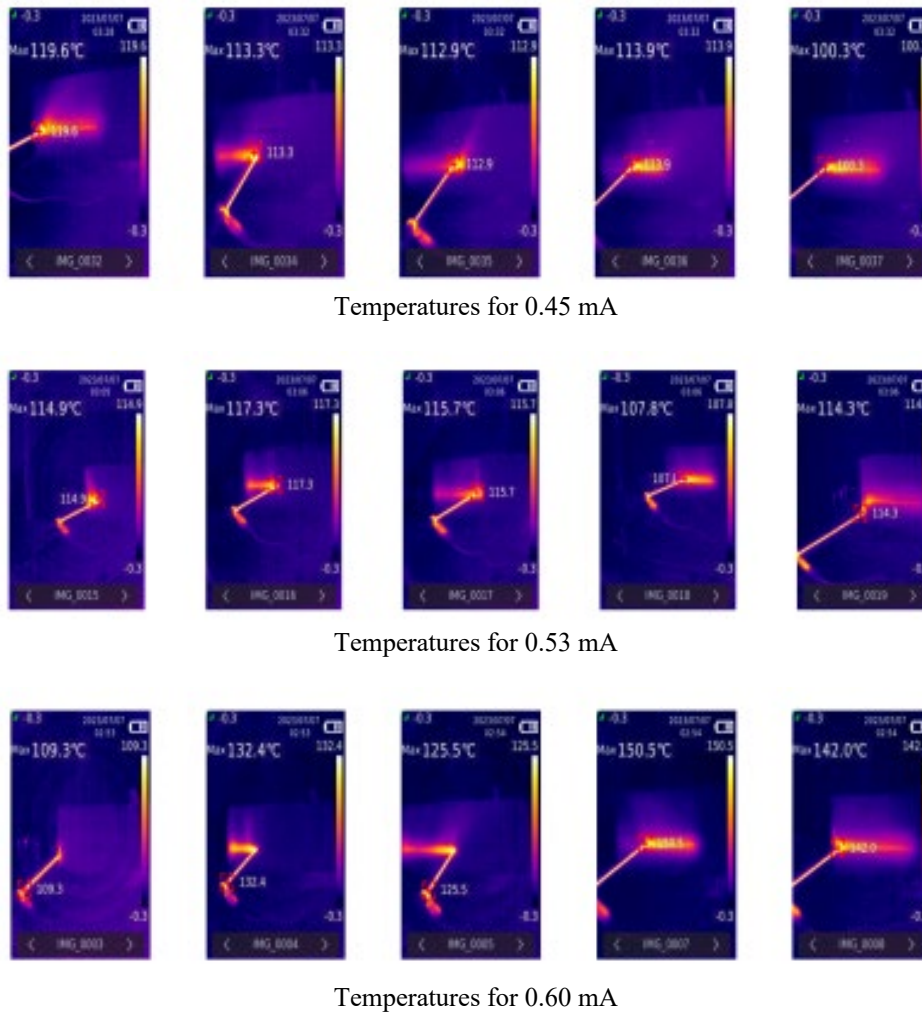


Figure 14. Temperature fluctuations on different current flow

Furthermore, when the cutting length grows, the temperature of the wire varies constantly. Figure 14 illustrates how the wire temperature fluctuates proportionately to the wire's supply current. With a 0.53mA current flow, the figure indicates the least amount of fluctuation in temperature with respect to the kerf width and the surface smoothness. This suggests the optimal range's precision as well. Here, Figures 14 depict the temperatures of the cutting wire during the cutting process.

5. Conclusion

This paper proposes parameters for cutting the Styrofoam with nichrome hot wire CNC Styrofoam Cutter. When the current flow through the nichrome wire increases, the temperature increases and expands. Thus, the foam vapors fast, and the design of the foam gets distorted. On the other hand, when the current supply is low, the wire needs more mechanical force to cut, increasing the friction and providing rough surface. Also, any assumed current supply cannot get the minimum temperature fluctuations of the wire. That is why optimized cutting parameters are needed for accurate and smooth cutting, which is 0.53 mA in this case. Operating the CNC machine in this parameter provides optimum kerf width, cutting time and minimum temperature fluctuations. The optimized parameters on other types of foams can be analyzed in the future. Also, instead of using nichrome wires, the cutting parameters of other wires and their effect on surface roughness can be optimized.

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Biographies

Md Soad Solaiman has recently completed BSc in Industrial and Production Engineering from the Military Institute of Science and Technology (MIST). His main research interests are optimization, simulation and mechatronics.

Md. Sakibul Islam Sakib has recently completed BSc in Industrial and Production Engineering from the Military Institute of Science and Technology (MIST). His main research interest in Machine Learning, Operation Research, Data Analysis.

Md Arifur Rahman has recently completed BSc in Industrial and Production Engineering from the Military Institute of Science and Technology (MIST). His main research interest is in optimization analysis.

Adib Bin Rashid has completed his MSc and BSc in Mechanical Engineering from the Military Institute of Science and Technology (MIST) and the Islamic University of Technology respectively. He is currently working as an assistant professor in the Industrial and Production Engineering Department of the Military Institute of Science and Technology, Dhaka, Bangladesh. His main research interests are thermal hydraulics, renewable energy, advanced material science, and additive manufacturing. He is a member of the Institute of Engineers, Bangladesh.